Exhibit VII B – Engineering Report: Return Flow Pipeline

Great Lakes Water Supply Program

GREAT WATER ALLIANCE

4-400 D1 Engineering Report: Return Flow Pipeline and Outfall Facilities

October 2019

DRAFT

Waukesha Water Utility
SERVING WAUKESHA SINCE 1886

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EXECUTIVE SUMMARY

The City of Waukesha Water Utility (WWU) provides water treatment and distribution services to a service area that includes the City of Waukesha (Waukesha), portions of the Town of Waukesha, and the City of Pewaukee. The St. Peter Sandstone aquifer, which has been the primary source of drinking water for Waukesha, has been severely depleted and is contaminated with naturally-occurring radium. Waukesha needs a long-term, sustainable alternative to its existing water supply to protect public health. After study efforts and public engagement, the Great Lakes-St. Lawrence River Basin Water Resources Council (Compact Council) issued its Final Decision unanimously approving Waukesha's Application to source water from Lake Michigan. WWU subsequently commissioned the Great Water Alliance (Program) to transition Waukesha's water supply. As part of the Program, approximately 23-miles of main (referred to as the "Return Flow Pipeline") is required per the Final Decision to achieve a net zero water balance in the Great Lakes–St. Lawrence River Basin by returning highly treated effluent to the Root River, which ultimately discharges into Lake Michigan.

Under the Wisconsin Administrative Code, Department of Natural Resources (NR), Chapter 108.04(2)(a), "All final plans and specifications submitted to the department pursuant to s. 281.41, Stats., and s. NR 108.03, shall be accompanied by a request for approval and by information pertinent to the design of the system, including general plans, construction details, specifications and an engineering report." The purpose of this Engineering Report: Return Flow Pipeline and Outfall Facilities (Report) is to satisfy this requirement for the Return Flow Pipeline and Outfall Facilities being implemented as part of the Program by summarizing the approach used for making key design decisions that supported the development of the drawings and specifications, including the following:

- Key design philosophies, including pipe materials, alignment, pipeline appurtenances, and corrosion control.
- The approach for modeling steady state hydraulics, designing pipe size, test pressures, pipe pressure class, and restrained joints, and determining normal operating conditions.
- The approach for modeling transient hydraulics, determining the type, size, and location for pipeline appurtenances required to mitigate hydraulic transients, and providing provisions for air management.

Route Study and Field Investigations

A route study was completed for the Return Flow Pipeline. Route alternatives were identified between a new Return Flow Pumping Station located at the City of Waukesha's Clean Water Plant (CWP) and the new Outfall Facilities located on the southeast quadrant of Oakwood Road and 60th Street in the City of Franklin. The route alternatives were evaluated based on economic and non-economic evaluation criteria and scored via a Triple Bottom Line analysis guided by the Envision Rating System for Sustainable Infrastructure. Route Alternative 3 shown in **Figure ES-1** was the selected route. Field investigations, including site survey, geotechnical, environmental, wetlands, waterways, endangered resources, and cultural resources were subsequently completed to support design.

Steady State Hydraulics

The Return Flow Pipeline is required to return the volume of water conveyed to Waukesha back to the Great Lakes-St. Lawrence River Basin. The Return Flow Pipeline was designed to convey flows reflective of Waukesha's water demand. The design capacity for the Return Flow Pipeline is based on the maximum day demand of 13.6 MGD during a year with an average day demand equivalent to the average day demand approved by the Compact Council of 8.2 MGD. A maximum instantaneous flow rate of 14.5 MGD was used as a secondary design criterion to accommodate flexibility in pumping schedules or the potential for future expansion of the Return Flow Pumping Station.

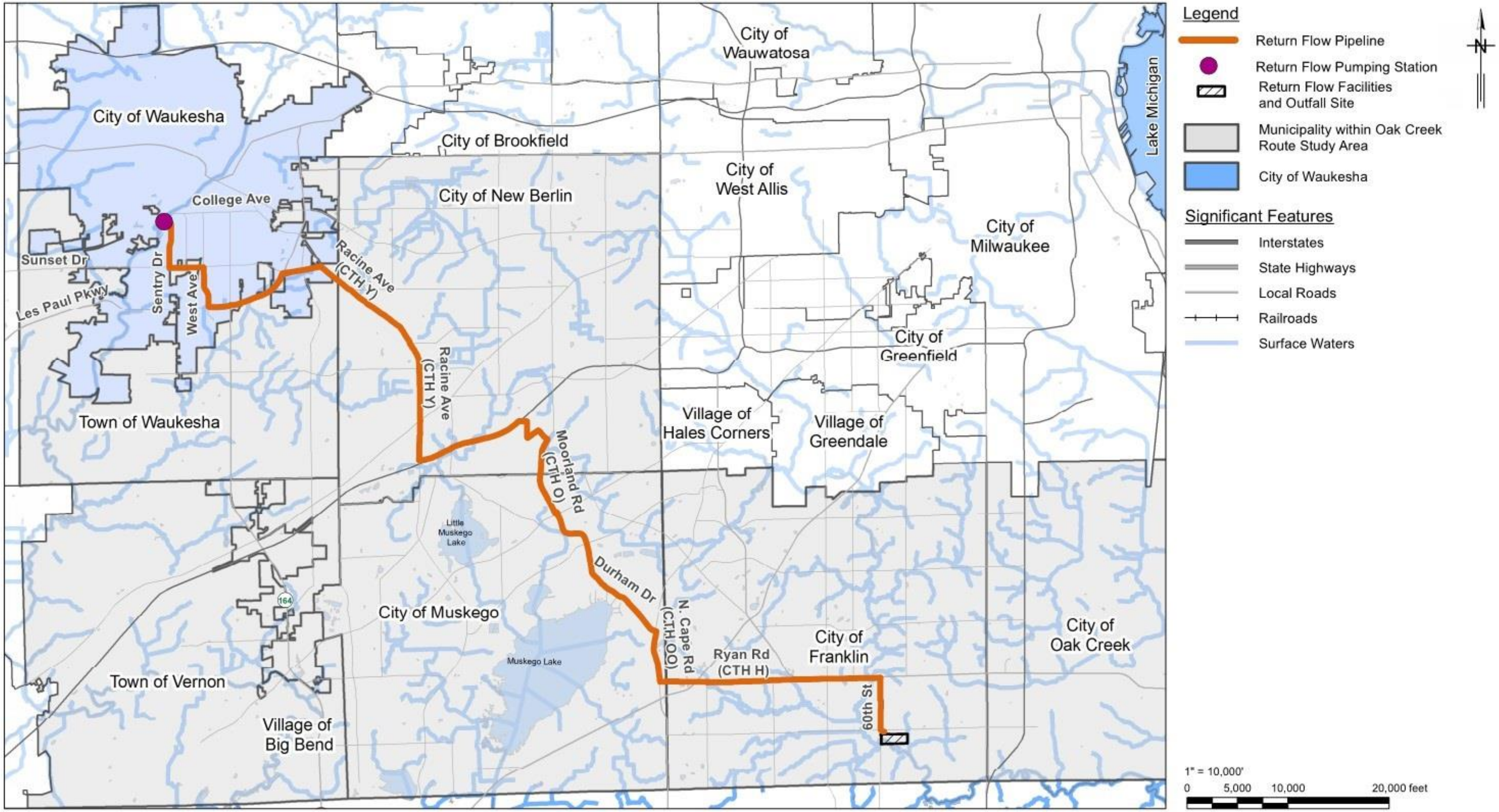


Figure ES-1 Return Flow Pipeline Route and Facilities

Steady State Hydraulics (continued)

A steady state hydraulic model for the Return Flow Pipeline was developed based on the pipeline alignment. Topography allows the ability for the Return Flow Pipeline to be operated as either a force / gravity main or entirely as a force main, which would allow the potential for energy recovery and water reuse in the future with additional infrastructure required at the Outfall Facilities. The Program determined the Return Flow Pipeline will be initially operated as a force / gravity main, but would be designed to allow for either hydraulic condition to be conveyed in the future. Thus, hydraulics for the Return Flow Pipeline were simulated as both a force / gravity main and entirely as a force main from no flow (static conditions) to 14.5 MGD. From the hydraulic analysis, a 30-inch Return Flow Pipeline size was selected. Test pressures were determined in accordance with American Water Works Association (AWWA) C600, and pipe pressure classes and restrained joints were designed based on the test pressures.

Design Philosophy

Pipe materials and joints were designed based on pipe size, hydraulics, constructability, WWU familiarity with material, and cost. To mitigate corrosion and provide for a longer service life, the Return Flow Pipeline was designed with two layers of polyethylene encasement – an inner layer consisting of V-Bio® Enhanced Polyethylene Encasement and an outer layer of standard polyethylene encasement, as well as sacrificial galvanic magnesium anodes, bonded joints, and test stations. The test stations will allow the ability to periodically monitor for corrosive signatures during operations so that proactive corrosion mitigation measures can be implemented if needed.

The horizontal and vertical alignments were developed for the pipeline considering pipe materials, joints, and construction methods, including open-cut and trenchless construction. Construction methods were selected based on surface features, existing utilities, and cost. Trenchless construction was utilized in areas where open-cut construction was not specifically preferred due to surface features or permit requirements. Horizontal and vertical alignments of the pipeline were designed beyond pavement where feasible to reduce cost due to pavement replacement, flowable or select fill, and maintenance of traffic. Trenchless construction via jacking and boring was utilized as a means of mitigating surface disruption at rail and major road crossings and horizontal directional drilling (HDD) was utilized to cross waterways and select wetlands. Limits of construction were designed to accommodate the construction method and pipeline appurtenances.

Pipeline appurtenances were designed for operations and maintenance as follows.

- **Isolation Valves:** The pipeline was designed with butterfly valves that will serve to isolate portions of the pipeline for maintenance and repair scenarios. Isolation valves were placed at approximately two-mile intervals, while some valves were shifted towards trenchless construction segments to minimize additional restrained joint length. Isolation valves were designed to be direct-buried except where specifically required to be located in vaults by the Wisconsin Administrative Code.
- **Blow-Off Assemblies:** Blow-off assemblies, consisting of a tee, branch, gate valve, and riser pipe, were placed at local low points in the vertical alignment to provide a means for draining the pipeline during startup, maintenance, or repair scenarios.
- **Air Valve Assemblies:** Air valves were placed at local high points along the vertical alignment to provide provisions for air management and transient mitigation. The air valve assemblies were designed in vaults with provisions for accessing the inside of the pipeline for inspection purposes at maximum intervals of 8,000 feet.

Transient Hydraulics and Air Management

A transient hydraulic model for the Return Flow Pipeline was developed in Liquid Transients (LIQT) software based on the pipeline alignment. Hydraulics were simulated for a sudden loss of power and stoppage of pumping while conveying 14.5 MGD. Transient mitigation devices in the form of air valve assemblies and a surge tank located at the new Return Flow Pumping Station were designed to mitigate hydraulic transients. Air valve assemblies were also designed to maintain capacity during normal operation by releasing entrained air and to accommodate filling and emptying during startup and operations.

SECTION 1 Introduction

1.1 Purpose

Under the Wisconsin Administrative Code, Department of Natural Resources (NR), Chapter 108.04(2)(a) – Requirements For Plans And Specifications Submittal For Reviewable Projects And Operations Of Community Water Systems, Sewerage Systems And Industrial Wastewater Facilities: Plans for Reviewable Projects, Submission of Final Plans and Specifications, "All final plans and specifications submitted to the department pursuant to s. 281.41, Stats., and s. NR 108.03, shall be accompanied by a request for approval and by information pertinent to the design of the system, including general plans, construction details, specifications and an engineering report." The purpose of this Engineering Report: Return Flow Pipeline and Outfall Facilities (Report) is to satisfy this requirement for the Return Flow Pipeline, a conveyance asset that will support the City of Waukesha's new Lake Michigan water supply being implemented as part of the Great Water Alliance (Program). The Report has been developed to include basis of design items applicable to the Program's Return Flow Pipeline and Outfall Facilities by summarizing the approach used in making key design decisions that supported the development of the drawings and specifications. The Report has been organized as follows:

1. **Section 1: Introduction**, including Program background and Return Flow Pipeline purpose and description.
2. **Section 2: Pipeline Route and Field Investigations**, including Return Flow Pipeline location, route study, field investigations, and utility coordination used to support design.
3. **Section 3: Steady State Hydraulics**, including population, demand projection, design flow rates, and the approach for modeling steady state hydraulics used to determine pipe size, normal operating conditions, topography, test pressures, pipe pressure class, restrained joint design, and special coating requirements.
4. **Section 4: Design Philosophy**, including the approach for selecting or designing pipe materials, pipe joints, horizontal and vertical alignment, construction methods, limits of construction, pipeline appurtenances, and operation and control.
5. **Section 5: Transient Hydraulics and Air Management**, including the approach for modeling transient hydraulics and determining the type, size, and location for pipeline appurtenances required to mitigate hydraulic transients and manage air.
6. **Section 6: Program Return Flow Pipeline and Outfall Facility Costs**, including the AACE International Class 1 Opinion of Probable Construction Cost (OPCC) and Operation, Maintenance, and Replacement (OM&R) Costs for the Return Flow Pipeline and Outfall Facilities.
7. **Section 7: Conclusions**, including a summary of key design aspects of the Return Flow Pipeline and Outfall Facilities.
8. **Section 8: References**, including key references used to support the design of the Return Flow Pipeline and Outfall Facilities.

For information on work in floodplains and wetland impacts, refer to the Wetland and Waterway Impact Permit Application submitted to WDNR in June 2019.

1.2 Great Water Alliance Overview

The City of Waukesha Water Utility (WWU) provides water treatment and distribution services to a service area that includes the City of Waukesha (Waukesha), portions of the Town of Waukesha, and the City of Pewaukee. The St. Peter Sandstone aquifer, which has been the primary source of water for Waukesha has been severely depleted in Southeast Wisconsin and is contaminated with naturally occurring radium. This is due in large part to a natural layer of shale rock that restricts groundwater recharge. Depletion of the St. Peter Sandstone aquifer has caused increases in the concentrations of radium and other contaminants. As a result, Waukesha needs a long-term, sustainable alternative to its existing water supply to protect public health.

In 2009, the Department of Justice (DOJ) issued a Stipulation and Order for Judgment to WWU to enforce state drinking water radionuclide standards. In October 2013, following study efforts and public engagement, Waukesha resubmitted its Application for Lake Michigan Diversion with Return Flow (Application) to the Wisconsin Department of Natural Resources (WDNR). In it, Lake Michigan water was determined to be the only reasonable sustainable source of water that protects both the environment and public health. WDNR concurred that Waukesha's proposal met the criteria of the Great Lakes-St. Lawrence River Basin Water Resources Compact (Compact) and submitted the Application to the Great Lakes-St. Lawrence River Basin Water Resources Council (Compact Council) for review. In its Final Decision, dated June 21, 2016, the Compact Council unanimously approved Waukesha's Application to source water from Lake Michigan as Waukesha's only reasonable water supply alternative.

WWU commissioned a team to implement the Program to transition Waukesha's water supply to Lake Michigan water. The purpose of the Program is to plan, design, construct, and commission infrastructure with a 100-year useful life necessary to transition Waukesha's water supply. Approximately 11-miles of transmission mains (referred to as the "Water Supply Pipeline" and the "Booster Pumping Station (BPS) Discharge Pipeline") with pumping facilities, water reservoirs, and chemical treatment will deliver water from Lake Michigan to Waukesha from the City of Milwaukee (Milwaukee). Approximately 23-miles of main (referred to as the "Return Flow Pipeline") is required by the Compact Council's Final Decision to achieve a net zero water balance in the Great Lakes–St. Lawrence River Basin. Refer to **Figure 1-1** for the Program vicinity map.

Key Program Elements associated with Waukesha's water supply transition were identified. The Program Elements are listed below, following the flow path along the water supply and return flow systems as shown in **Figure 1-2**. Some of these Program Elements have been designed and will be bid under the contract packages shown in **Figure 1-2**.

1. **Water Connection at Water Supplier:** A connection will be required to draw water from the Milwaukee Water Works (MWW) Distribution System.
2. **Oklahoma Pumping Station (OPS):** The OPS will be required to provide the head necessary to convey water to Waukesha through the Water Supply Pipeline. The OPS will be owned and operated by MWW.
3. **Water Supply Pipeline and Appurtenances:** A Water Supply Pipeline will be needed to convey water from the OPS to the water reservoirs at the Booster Pumping Station (BPS).
4. **Water Reservoirs:** Water reservoirs will be required between the OPS and Waukesha to attenuate demands and provide for storage. An air break will be provided at the water reservoirs to prevent backflow from the water reservoirs in the event of Water Supply Pipeline failure.
5. **Booster Pumping Station (BPS):** A BPS will be required to provide the head necessary to convey flow from the water reservoirs to the Water Supply Control Building (WSCB).

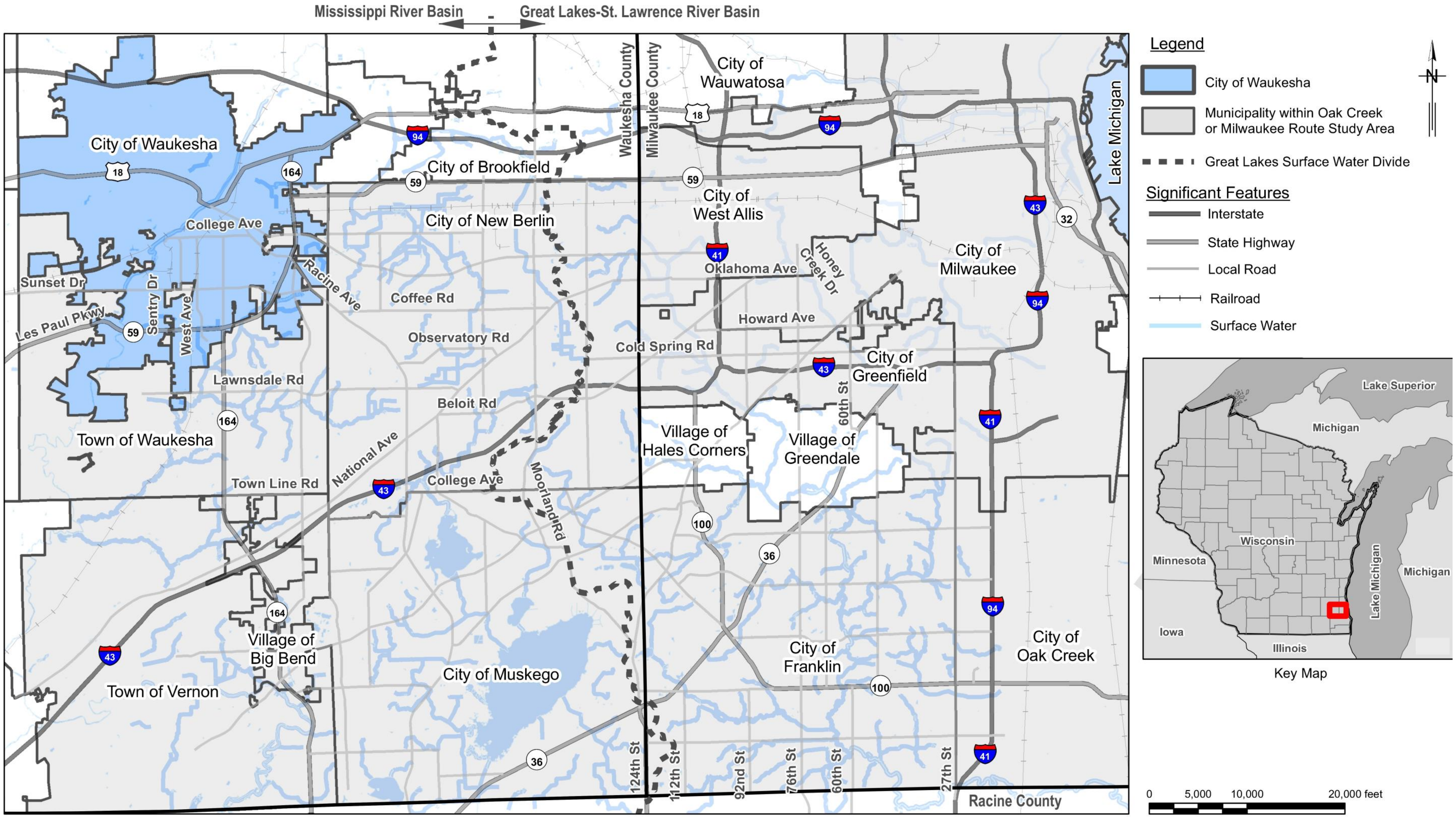


Figure 1-1 Program Vicinity Map

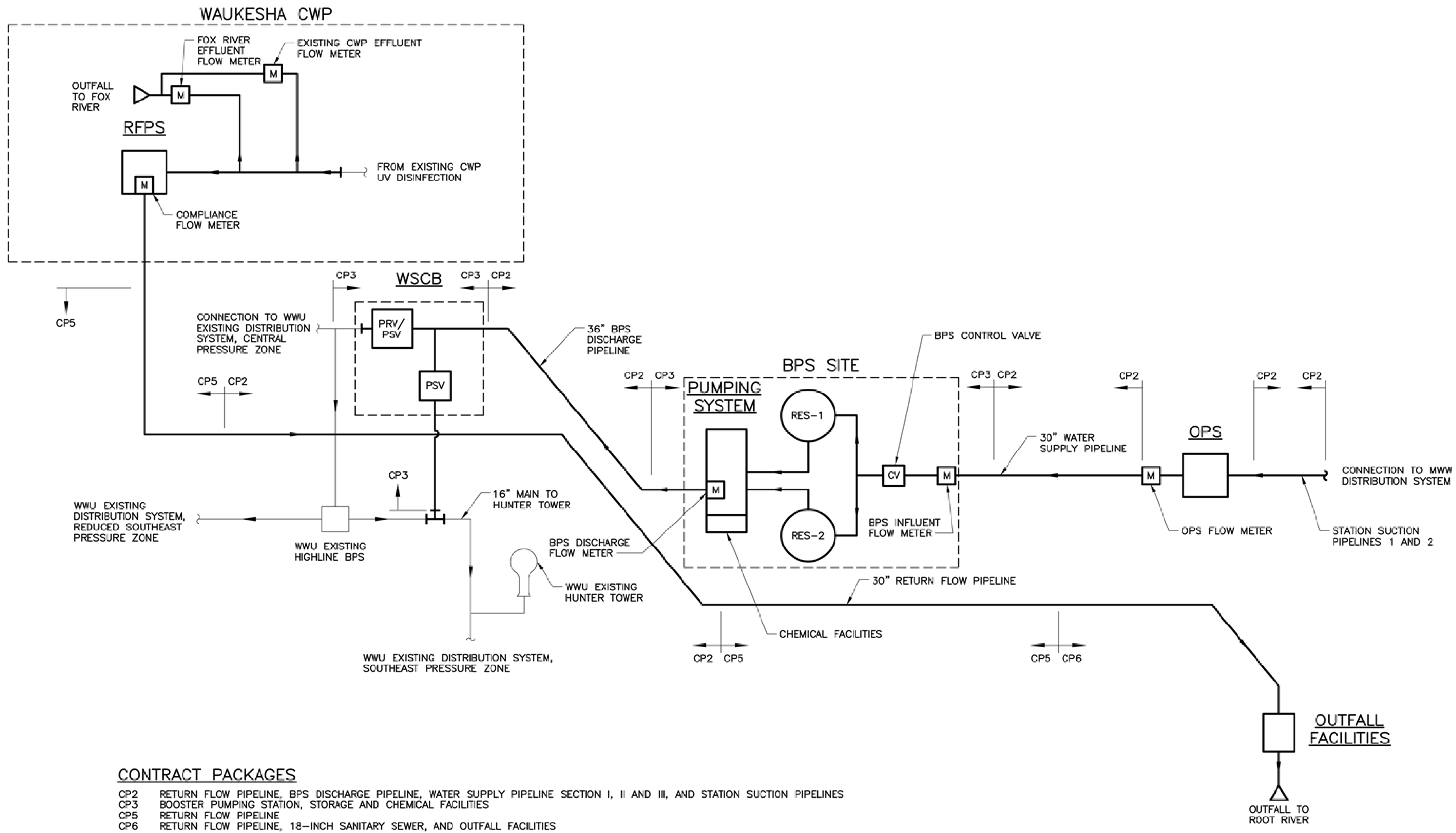


Figure 1-2 Program Diagram

6. **Chemical Feed Facilities:** Chemical feed facilities will be required at the BPS to provide the ability to adjust water quality characteristics, such as residual disinfectant levels.
7. **BPS Discharge Pipeline:** A BPS Discharge Pipeline will be required to convey flow from the BPS to the WSCB.
8. **Water Supply Control Building (WSCB) and Water Connection to Waukesha:** A WSCB will be required upstream of the connection to maintain discharge pressures to within desirable ranges for WWU's Distribution System. A connection will be required downstream of the WSCB to supply WWU's Distribution System.
9. **WWU Distribution System Improvements:** WWU's Distribution System is currently supplied by geographically disperse groundwater wells. The new water supply will feed the distribution system from one connection point. Therefore, improvements could be required at future demand conditions to accommodate the pressure distribution resulting from the new water supply.
10. **Return Flow Pumping Station (RFPS):** A RFPS will be required to provide the head necessary to convey highly treated effluent from Waukesha's Clean Water Plant (CWP) to the Root River. The RFPS will be owned and operated by Waukesha's Department of Public Works, and designed to satisfy their standards and preferences.
11. **Return Flow Pipeline and Appurtenances:** A Return Flow Pipeline will be required to create a net zero water balance in the Great Lakes–St. Lawrence River Basin.
12. **Outfall Facilities at Root River:** Facilities at the Root River outfall will be used to provide a means for discharging highly treated effluent to the Root River. A reaeration structure will be provided to provide dissolved oxygen adjustment prior to discharge.

SECTION 2 Pipeline Route and Field Investigations

2.1 Route Study

A route study was completed to determine a route for the Return Flow Pipeline. The following subsections summarize the background and route study for the Return Flow Pipeline. Refer to the Wetland and Waterway Impact Permit Application submitted to WDNR in June 2019 for further details summarizing the route study.

2.1.1 Background

In the Application, the City of Oak Creek (Oak Creek) was the preferred Lake Michigan water supplier. In late 2016, six possible pipeline routes and facility locations were considered in a screening-level analysis for an Oak Creek water supply with a Return Flow Pipeline to the Root River. Based on an economic and non-economic evaluation, three of the six route alternatives were selected and further evaluated as part of the Route Study: Oak Creek (Oak Creek Route Study), which was used to identify the preferred route that will be used to return highly treated effluent to the Root River through the Return Flow Pipeline. Milwaukee had not agreed to negotiate as a potential water supplier at the time of the Application but, in 2017, provided an unsolicited proposal to supply water to Waukesha. Milwaukee was then selected to be the Lake Michigan water supplier for the Program due to cost savings to WWU ratepayers. The Route Study: Milwaukee (Milwaukee Route Study) was subsequently completed to evaluate additional water supply corridors for a Milwaukee water supply. The route for the Return Flow Pipeline to the Root River remained consistent with the route selected from the Oak Creek Route Study. The following subsections summarize the Oak Creek Route Study completed for the Return Flow Pipeline.

2.1.2 Starting and Ending Points of Connection

Route alternatives were identified between known or potential points of connection for the Return Flow Pipeline described in the following subsections. Each connection point location provided boundary conditions for the route study area and served as the starting and ending points of the Return Flow Pipeline.

2.1.2.1 Return Flow Pumping Station (RFPS) at City of Waukesha's Clean Water Plant (CWP)

The Return Flow Pipeline will start at a new RFPS at the CWP located on Sentry Drive in Waukesha. Waukesha's Department of Public Works submitted a Facility Plan Amendment for the RFPS and wastewater treatment upgrades required to meet the anticipated Wisconsin Discharge Pollution Elimination System (WPDES) permit conditions on August 30, 2018. WDNR subsequently issued their approval of the Facility Plan Amendment on February 11, 2019. The location of the RFPS is shown on **Figure 2-1**. The Ultraviolet (UV) Disinfection Facility is outlined in white and the RFPS is shown by the black hatched box.

2.1.2.2 Outfall Facilities

The Return Flow Pipeline will discharge into the Root River as stipulated in the Final Decision by the Compact Council. WWU obtained an option to purchase property located at the southeast quadrant of Oakwood Road and 60th Street in the City of Franklin on Parcel 9489998001. The entire property is shown outlined in white on **Figure 2-2**. The property will serve as the Return Flow Pipeline's Outfall Facilities.

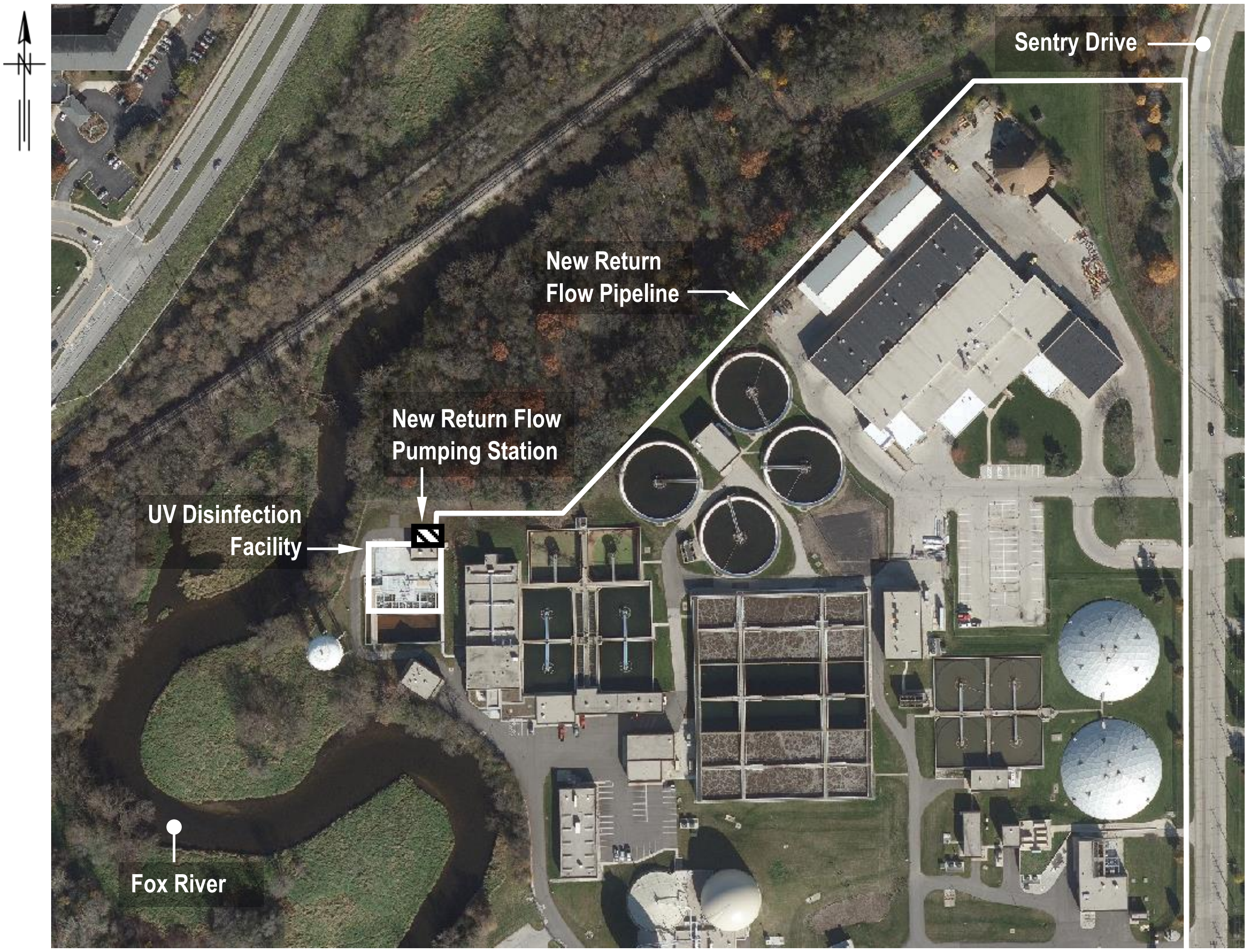


Figure 2-1 Clean Water Plant Site and Return Flow Pumping Station Locations

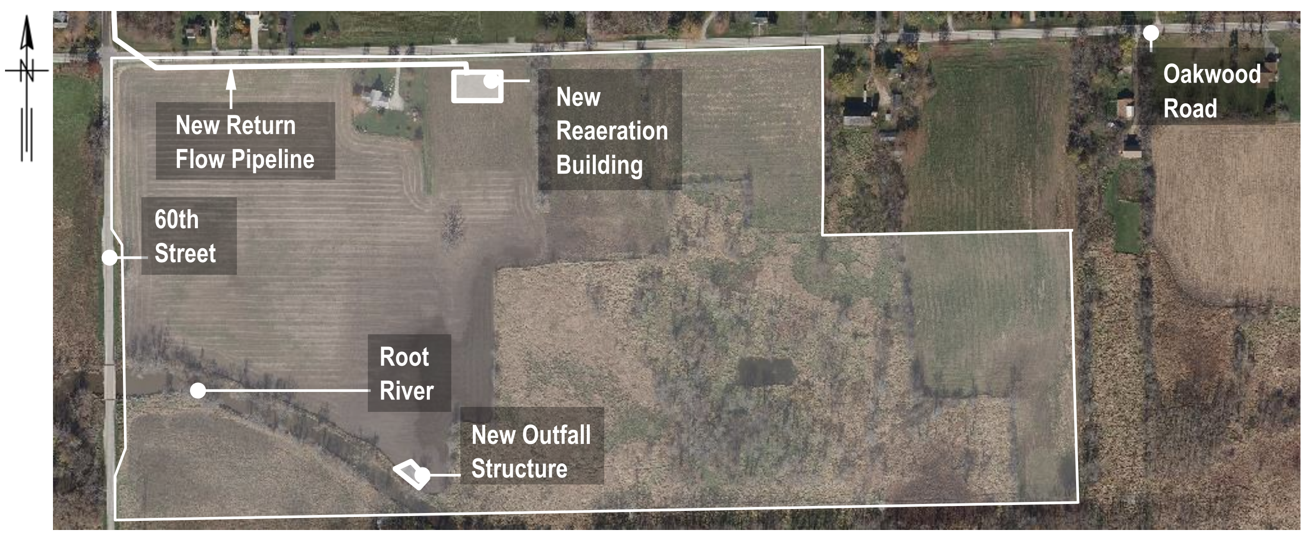


Figure 2-2 Outfall Facilities Location

2.1.3 Evaluation Criteria

Route alternatives were evaluated on the basis of economic and non-economic evaluation criteria. Non-economic evaluation criteria include characteristics or special requirements associated with each route alternative. The economic and non-economic evaluation criteria include the following items:

- Hydraulic analysis
- Total pipeline length
- Trenchless requirements
- Geotechnical conditions
- Contaminated materials
- Maintenance of traffic requirements
- Wetlands
- Waterways
- Floodplain encroachment
- Endangered resources
- Protected resources
- Agricultural resources
- Energy consumption
- Stakeholder feedback
- Real property and easement requirements
- Constructability
- Conceptual OPCC

The criteria were evaluated based on desktop assessments, field reconnaissance studies, and public Open House Meetings in which the public provided input on route alternatives. Preliminary horizontal alignments, special crossings, and steady state hydraulics were developed to compare the route alternatives on an economic basis. Class 4 OPCCs were prepared in accordance with AACE International’s Recommended Practice No. 18R-97. Costs were developed at an Engineering News-Record Construction Cost Indices (ENR CCI) value of 10,942 for June 2017 with a contingency of 25 percent and rounded to the nearest hundred thousand dollars. Based on the economic and non-economic evaluation, Route Alternatives 2, 3, and 4 shown in **Figure 2-3** were selected for further evaluation.

Route Alternatives 2, 3, and 4 were further evaluated based on Key Performance Indicators (KPIs), which were used to refine the evaluation to incorporate the concepts of a Triple Bottom Line (TBL) analysis guided by the Envision Rating System for Sustainable Infrastructure. KPIs were developed to integrate WWU’s values into the design process and provide a basis for developing metrics to evaluate and compare route alternatives. The KPI definitions were developed to be broad enough to apply to all aspects of the Program and act as universal weighting criteria. WWU staff weighted the KPIs from one (to represent a less significant or lower perceived impact to the Program) to ten (to represent a more significant or higher perceived impact to the Program). All of the weights were linearly scaled such that the sum of all weights produced a sum of 100. The KPIs were weighted from one (to represent a KPI of less importance) to ten (to represent a KPI of greater importance) to allow the evaluation to consider WWU preferences. The KPIs are listed by descending weight in **Table 2-1** alongside their definition using language from the Envision Rating System for Sustainable Infrastructure.

Data and information from the economic and non-economic evaluation were used to develop metrics for the KPIs. These metrics, in conjunction with input and feedback obtained during the Open House Meetings with stakeholders, were quantified and assigned to corresponding KPIs. **Table 2-2** displays the metrics selected and the KPIs to which they were assigned.

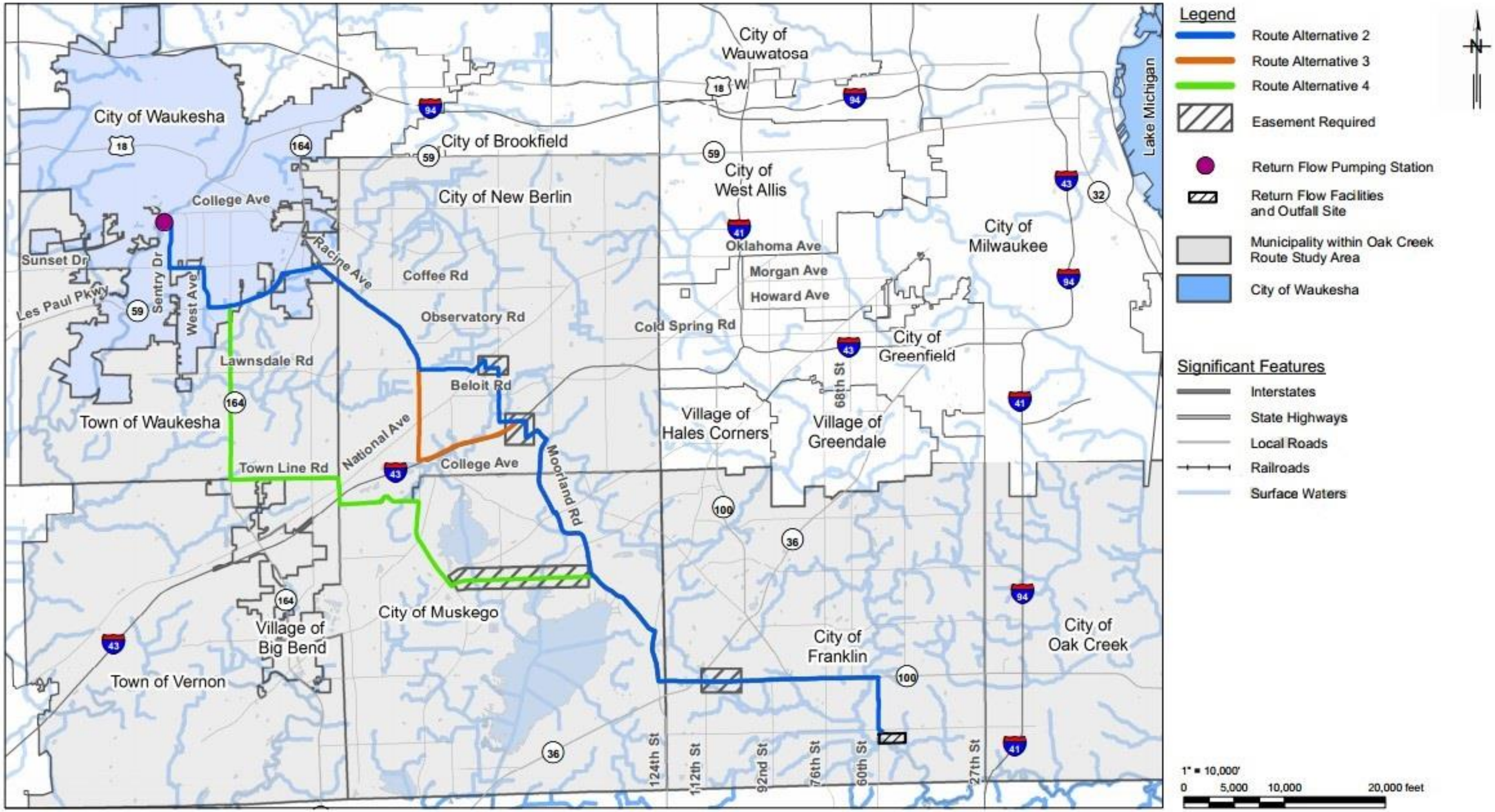


Figure 2-3 Route Alternatives 2, 3, and 4

Table 2-1 Key Performance Indicator Summary

Key Performance Indicator	Definition	Weighting
System Reliability	Using robust design strategies, preventive maintenance and intuitive configurations, Program Elements are dependable and resilient.	19.0
Life Cycle Cost	Pursue strategies that reduce long-term operational and maintenance costs.	15.5
Schedule	Complete the Program in a timeframe that mitigates negative impacts on the community's quality of life.	14.0
Ease of Construction	Avoid sites that require intensive efforts to preserve or restore, integrate infrastructure, or access with construction equipment.	11.0
Public Acceptability	The Program vision and goals align with those of the affected communities, and the implementation of the Program expands the skills, capacity, mobility, and health of a community while mitigating negative impacts.	6.5
Capital Cost	Minimize financial impact on the community with consideration of factors such as resource conservation, ease of infrastructure integration, and avoiding site development that requires additional efforts to preserve.	6.0
Effects on Ability to Finance	Through triple-bottom line analysis, Program Elements have been de-risked and future-proofed, helping attract infrastructure investment.	6.0
Future Expansion	Implement designs and other measures that allow for the expansion of the Program to incorporate Compact Council approved future connections and increased flow without requiring additional infrastructure and capital expenditure.	6.0
Operational Flexibility	Reduce vulnerabilities by creating an adaptable design that can function in a variety of social, economic, and environmental conditions with monitored systems that allow ease and consistency of operation.	6.0
Environmental Impact	Measures are taken to preserve the natural world through avoidance, monitoring, restoration, and negative impact mitigation; resources are conserved during the construction and operation of the Program; there is a concerted effort to preserve the ambient conditions that affect quality of life of the community like noise, light, and air quality.	5.0
Cost Sharing Potential	Thorough infrastructure integration and commitment to synergistic opportunities, the cost of Program Elements is shared by a broader community.	5.0
	Total	**100.0**

Table 2-2 Metrics Delineated into KPIs

Key Performance Indicator	Metrics
System Reliability	Length of Pipe (LF), Accessibility (Number of Special Crossings, Number of Easements), Maximum Pressure (psi)
Life Cycle Cost	Capital Cost (Dollars), Energy Cost (Dollars)
Schedule	Days (Determined by Linear Feet of Pipe / Day)
Ease of Construction	Depth to Bedrock (LF of Pipe < 50ft deep), Dense Soils (LF of Pipe), Organic Soils (LF of Pipe), Shallow Groundwater, Soils Corrosive to Steel/Ductile Iron (LF of Pipe), Soils Corrosive to PCCP (LF of Pipe), Contaminated Materials (Total Ranking Score on each Route)
Public Acceptability	Cultural Resources (No. of Archaeological, Burial, and Historic Sites), Transportation (Linear Feet of Roadway Impacts, Square Footage of Pavement Area, Additional Driving Hours), Number of Easements, Agriculture (Acreage in the Easements), Coordination with Planned Regional Transportation Projects
Capital Cost	Capital Cost (Dollars)
Effects on Ability to Finance	Envision Score[1]

Key Performance Indicator	Metrics
Potential Future Expansion[2]	Growth potential within City of Waukesha, Number of Municipalities Traversed, Average Day Demand of Municipalities Traversed (MGD)
Operational Flexibility	Number of Pressure Sustaining Valves, Number of Connections to the Distribution System, Distribution System Pressure (psi)
Environmental Impact	Acreage of Wisconsin Wetland Inventory (WWI) Mapped and Photo-Interpreted Wetlands, Number of Waterways Crossed
Cost Sharing Potential	Number of Municipalities Traversed, Simultaneous Planned Regional Transportation Projects

Notes:
1. Sustainable projects are more likely to receive financing from different entities.
2. Potential future expansion of Waukesha's water system would need to be approved by the Compact Council.

2.1.4 Return Flow Pipeline Evaluation

The TBL evaluation incorporates three dimensions of performance: social and community, economic, and environmental. The KPIs were delineated into the dimensions of performance to which they best corresponded. Route Alternatives 2, 3, and 4 were scored from one (to represent a less favorable alternative for the established KPI) to five (to represent a more favorable alternative for the established KPI) based on each route alternative's performance for each evaluation criteria. These scores were entered into the TBL matrix shown in **Table 2-3**. The resulting products of the weighting and scores were compiled to produce a total score for each route shown at the bottom of the matrix where a higher score indicates a more preferable route alternative.

Table 2-3 Triple Bottom Line Evaluation for the Route Alternatives 2, 3, and 4

	Criteria	Weighting[1]	Maximum Possible Score	Route Alternative		
				2	3	4
1	**Social and Community Goals**					
1.1	Schedule	14.0	5	3	3	2
1.2	Public Acceptability	6.5	5	2	3	2
1.3	Operational Flexibility	6.0	5	3	3	4
1.4	Future Expansion	6.0	5	4	4	3
2	**Economic Goals**					
2.1	System Reliability	19.0	5	4	5	3
2.2	Life Cycle Cost	15.5	5	4	4	3
2.3	Ease of Construction	11.0	5	3	3	2
2.4	Capital Cost	6.0	5	4	3	2
2.5	Effects on Ability to Finance	6.0	5	3	4	2
2.6	Cost Sharing Potential	5.0	5	4	4	3
3	**Environmental Goals**					
3.1	Environmental Impact	5.0	5	4	3	2
	Net TBL Score[2]	**100**	**500**	**350**	**371**	**258**
	Percent of Max Possible Score		NA	**70%**	**74%**	**52%**

Notes:
[1] Weighting = Relative Importance Category Weight as Percent of Total of All Categories x Sub-criteria Internal Weighing Factor as Percent of Criteria Total x Sum of Criteria Total
[2] Net TBL Score = Sum of sub-criteria score x Weighting for each Alternative. Net TBL Scores were rounded to nearest whole number.

Although route scoring included both economic and non-economic considerations, review of Class 4 OPCCs have revealed route alternatives are economically comparable. The highest weighted KPIs were Schedule, System Reliability, Life Cycle Cost, and Ease of Construction. Route Alternative 4 scored less preferably than the other alternatives in these metrics and nearly every other KPI. The low scoring of Route Alternative 4 is principally attributed to the longer total pipeline length, longer trenchless requirements, and constructability concerns through the electrical transmission utility corridor along the City of Muskego (Muskego) Recreational Trail. Route Alternative 4 has the potential to have greater impacts to the environment, including potential impacts to wetlands, waterways, and endangered resources, and also has greater energy consumption than other alternatives. Route Alternative 4 has a higher OPCC than Route Alternatives 2 and 3. Route Alternative 4 is also located along corridors with more planned regional transportation projects and has stakeholder feedback concerns that may require pipeline rerouting, which could further elevate its capital costs. Considering these factors, Route Alternative 4 is less preferable than Route Alternatives 2 and 3.

Although Route Alternatives 2 and 3 scored comparably, Route Alternative 2 is routed through more narrow corridors that would cause greater public impacts and maintenance of traffic requirements than Route Alternative 3. Route Alternative 2 requires easements that have stakeholder concerns. Although Route Alternative 2 has a shorter total pipeline length and slightly lower OPCC than Route Alternative 3, Route Alternative 2 has a risk of rerouting that could result in longer total pipeline length due to stakeholder concerns. This could increase Route Alternative 2's capital cost above Route Alternative 3's capital cost.

Route Alternative 3 reduces challenges related to Route Alternative 2 by routing through the Interstate 43 corridor, which reduces public impacts and maintenance of traffic requirements. Route Alternative 3 requires fewer easements, traverses fewer near-term planned regional transportation projects, and received more favorable stakeholder feedback that yielded higher scores in System Reliability and Public Acceptability than Route Alternative 2.

The Program has been coordinating with the Wisconsin Department of Transportation (WisDOT) and the Federal Highway Administration (FHWA). A Hardship Application was submitted to WisDOT and FHWA. Approval for locating the Return Flow Pipeline within Interstate 43 right-of-way was received from FHWA and WisDOT on April 5, 2019 regarding the Hardship Application and on April 8, 2019 for the National Environmental Protection Act (NEPA) Categorical Exclusion Checklist (CEC).

2.1.5 Pipeline Route

Considering economic and non-economic evaluation criteria, Route Alternative 3 is the preferred route to return highly treated effluent to the Great Lakes-St. Lawrence River Basin. The route for the Return Flow Pipeline is shown in **Figure 2-4.**

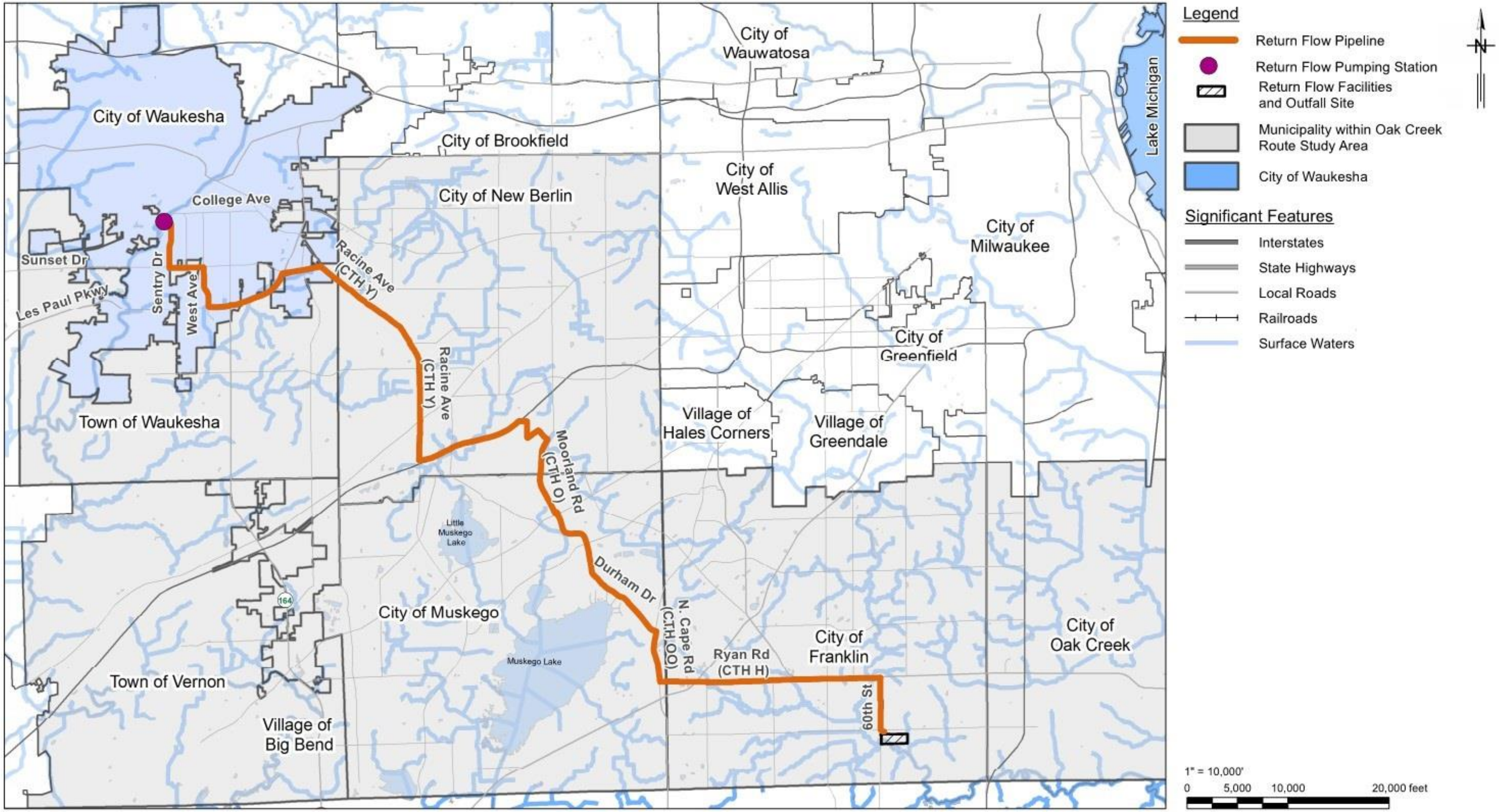


Figure 2-4 Return Flow Pipeline Route and Facilities

2.2 Field Investigations

Field investigations were performed to support design along the Return Flow Pipeline route, including site survey, geotechnical soil borings, contaminated materials investigations, delineating wetlands and waterways, and cultural resources, endangered resources, and agricultural resources investigations. These investigations are described within this subsection.

Site Survey: The site survey was conducted within the selected corridors and proposed permanent easements along the pipeline route. The utility and topographic survey data was used in the design of the horizontal and vertical alignments of the pipeline.

Geotechnical: The geotechnical field investigations were conducted and consisted of soil borings at increments of 1,000 feet to a minimum depth equivalent to two pipeline diameters below the anticipated pipeline invert elevation. Additional borings were taken at the beginning and ending points of select special crossings. The investigations provided information on the suitability of soils for pipeline appurtenances and structures that were incorporated in the design. Geotechnical field investigation tasks include the following items:

- Standard Penetration Test (SPT) borings drilled to 25-feet below grade (or shallower where bedrock is encountered) and a temporary piezometer and in-situ falling head permeability test every mile, sealed with bentonite if conditions require and plugged with grout.
- Pavement borings at approximately one-mile increments to determine thickness of pavement and subgrade.
- Seasonal high groundwater level at approximately one-mile increments.
- Soil environmental parameter analysis for corrosion control design at approximately 2,000-foot intervals, consisting of sulfate, chloride, pH, redox potential and conductivity.
- Compaction testing on suitable soils to be used for trench backfill.

Findings from the geotechnical field investigations were reviewed and pipeline design was coordinated with the findings from the geotechnical investigations. Geotechnical Reports will be made available to the contractors for their reference only during construction.

Contaminated Materials: Contaminated materials investigations were completed in conjunction with the geotechnical field work. Phase II Environmental investigations were performed along the pipeline alignments to identify the extent of impacts from known or likely sources of contamination that could affect the design, handling, disposal, Program schedule, or any other aspect needed for due diligence supported by soil samples collected during geotechnical investigations. The drawings and specifications were developed to delineate specific handling and disposal requirements based on findings from these investigations as required by WDNR. Phase II Environmental Reports will be made available to the contractors for their reference only during construction.

Wetlands and Waterways: Field investigations for wetlands and waterways were conducted along the pipelines to confirm findings from the desktop analyses. Wetland delineations were performed to verify mapped and photo interpreted wetlands along the corridors of the pipelines and within proposed permanent easements. The horizontal alignments were further developed in design to avoid wetland impacts to the extent feasible as described in the Wetland and Waterway Impact Permit Application submitted to WDNR in June 2019.

Endangered Resources: Field investigations for endangered resources were conducted along the pipelines to confirm findings from desktop analyses. The presence of endangered resources in proximity to the pipelines dictated certain requirements which have been incorporated into the Program design.

Cultural Resources: A complete literature and archives search was conducted, including a search of the Wisconsin Historic Preservation Database (WHPD), for the pipeline routes and facilities, and the Phase I archaeological survey for the routes, including some routes or segments of routes that are no longer part of the Program. The literature and archives research noted a number of historic sites and cemeteries that were once in the various proposed routes.

As the Phase I survey progressed, the majority of the identified historical structures along the studied Program routes were determined to not be impacted, including many that were determined to no longer exist but were not deleted from the WHPD. The Phase I survey identified five archaeological sites, one burial site, two cemeteries, and one potentially historic farmstead that are in the area of the Program routes.

As the development of the horizontal alignments for the pipelines progressed, and as a result of the Phase I archeological survey and Phase I+ survey, it was determined that one of the five identified archaeological sites will be in the vicinity of the Program construction. The limits of construction are outside the boundaries of the identified sites, and the construction in the area of the identified sites will be completed under the supervision of the Program Archaeologist. Descriptions of the Program sites and construction activities were sent to the Wisconsin State Historic Preservation Office (SHPO) for review. Representatives from SHPO will determine if any additional efforts will be required during construction around these sites.

Agricultural Resources: An agricultural resources impact assessment is an item required by the Public Service Commission (PSC) and the Wisconsin Department of Agriculture, Trade, and Consumer Protection (DATCP) in a construction project and as part of the Certificate of Public Convenience and Necessity (CPCN) process. The assessment is comprised of the anticipated impacts to agricultural resources, where fewer impacts are more preferable. An agricultural resources desktop assessment was conducted via review of locations of agricultural lands, quantity of agricultural lands, and types of agricultural lands using the Waukesha County Open Data Portal Website, Milwaukee County Land information Office Geospatial data, the USDA Organic Integrity Database, and the Organic Agriculture in Wisconsin 2017 Status Report and 2015 Status Report. For compliance with DATCP regulations, the Program submitted an Agricultural Impact Notice to DATCP in August 2018 to provide information for the Agricultural Impact Statement. In February 2019, DATCP determined that an Agricultural Impact statement will not be required for the Program.

2.3 Utility Coordination

Utility coordination was completed as part of design. Known utilities within corridors and proposed permanent easements of the pipelines are summarized in **Table 2-4**.

Table 2-4 Utility Source Descriptions

Utility	Description
ANR Pipeline	Gas
AT&T Distribution	Telecommunications/Fiber Optic
AT&T Transmission	Telecommunications/Fiber Optic
City of Franklin	Sanitary, storm, and water
City of Muskego	Sanitary, storm, and water
City of New Berlin	Sanitary, storm, and water
City of Waukesha	Sanitary, storm, and water

Utility	Description
Level 3 Communications	Telecommunications/Fiber Optic
Midwest Fiber Network	Telecommunications/Fiber Optic
Milwaukee County DPW	Traffic Signals
Milwaukee Metropolitan Sewerage District	Sanitary and landfill gas
Sprint Nextel	Telecommunications/Fiber Optic
TDS Metrocom	Telecommunications/Fiber Optic
TesInc	Telecommunications/Fiber Optic
Time Warner Cable	Telecommunications/Fiber Optic
Waukesha County DPW	Traffic signals
We Energies	Electric and gas
West Shore Pipe Line	Petroleum
Windstream	Telecommunications/Fiber Optic
WisDOT	Traffic signals

A standard utility coordination process was followed for the pipelines within the right-of-way corridors and proposed permanent easements to identify the presence and locations of existing utilities. The process is summarized below.

1. A planning ticket, which is a form to request as-built information from utilities, was submitted to the third party utility communication firm, Diggers Hotline. A list of utility companies was received that may have utilities in proximity to the pipeline.
2. Route location maps and utility information requests were sent to the utilities listed on the planning ticket from Step 1, by Diggers Hotline, to supply as-built drawing information of the respective utility. The information is stored in a Program information database and logged to confirm required utilities along the pipelines have been properly identified. If these utilities did not reply, they were re-contacted.
3. In the development of the drawings, general locations were documented from Step 2 and merged with utility information received from the site survey.
4. 60% drawings were shared with the utility companies and municipalities with a request to review their utilities on the drawings and meetings were held with the following municipalities and utilities to review the proposed alignment of the Return Flow Pipeline. The design was updated as necessary to coordinate with existing utilities based on feedback from the following meetings:
   - City of Franklin
   - City of Muskego
   - City of New Berlin
   - City of Waukesha
   - TesInc
   - Town of Waukesha
   - Milwaukee County
   - Waukesha County
   - We Energies
   - Wisconsin Department of Transportation
5. Potholing was performed by excavating a small hole via a vacuum truck to obtain X, Y, and Z coordinates of critical vertical crossings identified in Step 4, and the vertical alignment was updated as necessary. Potholing was utilized during design where the pipeline is crossing utilities without manholes, vaults, or any structure that can be utilized to interpret the given utility's vertical alignment.

SECTION 3 Steady State Hydraulics

Steady state hydraulics were used to determine pipe size, pressure class, restrained joint lengths, and pressure test requirements. The following subsections describe the approach to design these items for the Return Flow Pipeline.

3.1 Flows

The Return Flow Pipeline is required to return the volume of water conveyed to Waukesha back to the Great Lakes-St. Lawrence River Basin. The flows were developed based on the Compact Council's Final Decision, which was based on a buildout population of 76,330 for 2050 from Southeast Wisconsin Regional Planning Commission (SEWRPC) estimates. The Return Flow Pipeline flows are anticipated to reflect Waukesha's demand as follows:

- **Static Conditions:** **Static conditions (no flow)** was considered in the hydraulic analysis.
- **Minimum Flow Rate:** The minimum flow rate is anticipated to be **1.2 million gallons per** day (MGD), which was calculated based on the minimum day demand observed in Waukesha from January 2007 through December 2016 multiplied by the minimum peaking factor observed of 0.4.
- **Initial Average Day Demand:** The initial median flow rate will be approximately **6.6 MGD**, which is the median water demand observed in Waukesha from January 2007 through December 2016.
- **Approved Average Day Demand**: The average flow rate is anticipated to reach an ultimate value of **8.2 MGD**, which is the average day demand approved by the Compact Council.
- **Design Capacity:** The design capacity of the Return Flow Pipeline is based on a flow rate of **13.6 MGD,** which is the maximum day demand anticipated during a year where the average day demand is 8.2 MGD. A maximum instantaneous flow rate of **14.5 MGD** was used as a secondary design criterion to accommodate flexibility in pumping schedules or the potential for future expansion of the RFPS.

The above flow rates were developed in coordination with water demand in order to size the return flow system such that the Return Flow Pipeline would be capable of returning the volume of water conveyed to Waukesha back to the Great Lakes-St. Lawrence River Basin.

3.2 Roughness Coefficients

3.2.1 Methods

Two roughness coefficients have been used in characterizing major head losses from flow conveyance as follows:

- Manning's Resistance Coefficient (referred to as "n")
- Hazen-Williams Roughness Coefficient (referred to as "C")

Manning's formula is typically used to hydraulically model open channel conditions, where n accounts for major friction losses. Manning's formula can be expressed as:

$$Q = \frac{k}{n} R_h^{2/3} S^{1/2} A$$

in which Q is flow rate, A is conveyance area, S is slope of the hydraulic grade line (HGL) (assumed equivalent to pipe slope), Rh is hydraulic radius (calculated as A divided by wetted perimeter, Pw), and k is 1.486 for English units. Methods using Manning's formula typically use a constant value for n based on the material or age of a given pipe or channel. Manning's formula was used for accounting for major head losses along the open channel portions of the Return Flow Pipeline.

The Hazen-Williams formula is typically used to hydraulically model full-pipe flow, where C accounts for major friction losses. The Hazen-Williams formula can be expressed as:

$$Q = 1.318 C R_h^{0.63} S^{0.54} A$$

in which Q is flow rate, A is conveyance area, S is the slope of the HGL, and R_h is hydraulic radius. Methods using the Hazen-Williams formula typically uses a constant value for C based on the material or age of a given pipe. The Hazen-Williams formula and its use of C is analogous to Manning's formula and its use of n in open channel applications. The Hazen-Williams formula was used for accounting for major head losses along pressurized portions of the Return Flow Pipeline.

3.2.2 New and Aged Pipe

Pipeline age was evaluated to project the increase in major head losses in the Return Flow Pipeline over a 100-year useful life. According to Table 5-6 of the reference text Open-Channel Hydraulics by Ven Te Chow, values for Manning's n typically range from 0.013 to 0.017 for open channel flow through closed concrete conduits. DIP will be furnished with cement-mortar lining, which would produce comparable hydraulic conditions. Thus, n values of 0.013 and 0.017 have been used to characterize major head losses along the Return Flow Pipeline in open channel conditions.

More emphasis was placed on defining C values, as C values have been used to model pressurized conditions that would dictate the pressure class and size of the Return Flow Pipeline. Regulations and guidance documents provide a recommended value or range of values for C. Although values for C vary based on pipeline material, pipeline age, and the type of fluid being conveyed, the regulation and guidance documents and manuals of practice do not distinguish between pipe age and material. Roughness coefficients for mains conveying either water or wastewater as provided by regulations and guidance documents and manuals of practice include the following items.

- **Ten States Standards**
  - Water: Recommended Standards for Water Works, 2012 Edition (Ten States Standards - Water)
  - Wastewater: Recommended Standards for Wastewater Facilities, 2014 Edition (Ten States Standards - Wastewater)

- **WDNR**
  - Water: Requirements for the Operation and Design of Community Water Systems, Wisconsin Department of Natural Resources Chapter (WDNR NR 811)
  - Wastewater: Sewerage Systems, Wisconsin Department of Natural Resources Chapter (WDNR NR 110)

- **WWU**
  - Water: Specifications for Water Main and Service Lateral materials and the Installation of Water Main and Appurtenances for Waukesha Water Utility, 2014 (WWU Specifications)

C values provided by regulations and guidance documents and manuals of practice were compared to flow test data for pipes after years of service. A study performed by the Ductile Iron Pipe Research Association (DIPRA) titled *Cement-Mortar Linings for Ductile Iron Pipe* dated March 2017 summarized the flow testing results performed on cement-mortar lined DIP. The pipes tested were water mains located in 20 cities across the United States. The water mains ranged in nominal diameter from six- to 36-inches and were in service from five- to 77-years at the time of flow testing. Due to the highly treated water quality characteristics of the Return Flow Pipeline, these flow test results have been considered applicable to the Return Flow Pipeline. **Figure 3-1** shows the flow test results overlaid upon C values provided by regulations and guidance documents and manuals of practice. A trend line of flow test data as a function of the power of pipeline age is overlaid upon the figure.

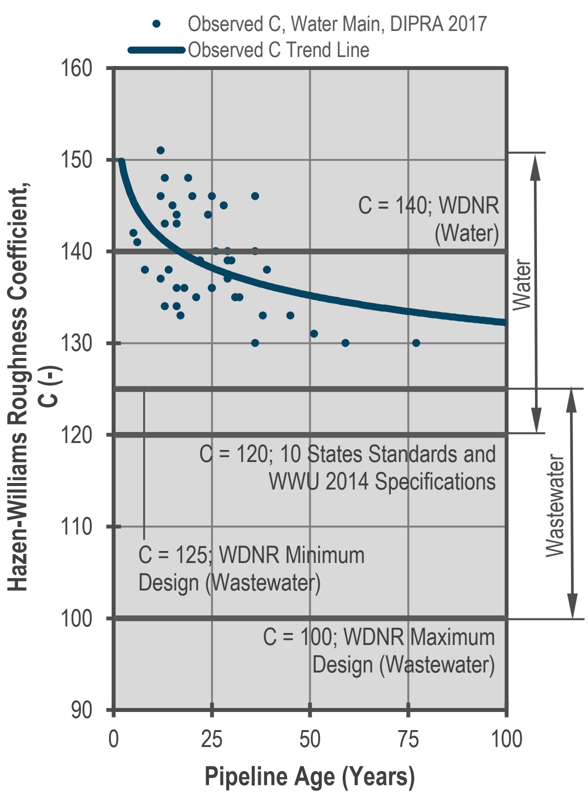


Figure 3-1 Hazen-Williams Roughness Coefficient Analysis with Pipeline Age

As shown in **Figure 3-1**, the regulations and guidance provide lower C values for pipelines conveying wastewater. The Return Flow Pipeline will convey highly treated effluent with lower suspended solids, organics, and nutrient content than that which exists in a raw sewage force main. Hydraulics through the Return Flow Pipeline are anticipated to be more comparable to that of a water main, rather than that of a raw sewage force main. As a result, C values below 120, representing hydraulic conditions typical for a raw sewage force main, have been determined to be unnecessarily conservative and not reflective of anticipated major head losses during the Return Flow Pipeline's useful life.

Flow testing data indicate a new pipeline could have C values as high as 150. The steady state hydraulic analysis should evaluate the full range of operating conditions anticipated for the purpose of sizing the pipeline and pumping facilities. Thus, C values of 120 and 150 have been used to characterize major head losses along the Return Flow Pipeline in pressurized conditions. The values are within the range provided by WDNR NR 110 as well as the recommended C value by Ten States Standards.

3.2.3 Scaled Pipe

Water producers in the Midwest have reported lower C values (just below C = 100) in some cases due to scaling and biofilms that develop on pipe surfaces. Although not utilized as a design criterion, C = 95 was used as a design check to confirm the pipeline wall thicknesses would be thick enough to withstand operational pressures that could result from conveying the maximum instantaneous flow rate through scaled pipe typical to that observed in the region.

3.3 Assumptions and Criteria

Assumptions and criteria have been used to support the hydraulic design of the Return Flow Pipeline as follows:

- **Return Flow Pumping Station (RFPS)**
  - Flows conveyed to Waukesha through the Water Supply Pipeline will be offset by an equal discharge to the Root River through the Return Flow Pipeline.
  - The RFPS will be located north of the UV Disinfection Facility at the CWP per the Waukesha Department of Public Works plan set titled Wastewater Treatment Plant Improvements, Phase II and dated January 2, 2015.
- **Return Flow Pipeline**
  - The maximum steady state design pressure will be 225 psi. This will eliminate the need for using a pipe with pressure class above 250 psi. Normal operating pressures in excess of 250 psi require thicker pipe walls and non-standard, more robust valves, which would increase cost and complexity of design.
  - The Return Flow Pipeline will be operated as a force main upstream of the hydraulic high point and a force / gravity main downstream. The Return Flow Pipeline will be designed with the ability to transition entirely to a force main in the future.
  - A maximum velocity of seven feet per second (fps) is desirable for pipeline sizing of the force main to maintain head losses within reasonable tolerance and conserve energy during pumping.
  - The Return Flow Pipeline will have a design capacity of 13.6 MGD. If the RFPS is expanded in the future, the Return Flow Pipeline will have a maximum instantaneous flow rate of 14.5 MGD.
  - The Return Flow Pipeline will be constructed of DIP with major head losses due to friction and hydraulic turbulence representative of the C and n values in **Table 3-1.** HDD segments comprised of HDPE pipe will impose comparable head loss as DIP.

Table 3-1 Roughness Coefficients

Item	Hazen-Williams C	Manning's n
Hydraulic Condition	Pressurized	Open Channel
New	C = 150	n = 0.013
Aged	C = 120	n = 0.017

  - Fittings and valves will induce minor head losses calculated as $K\frac{V^2}{2g}$ with K values as shown in **Table 3-2**.

Table 3-2 Minor Head Loss Friction Factors

Bends (Degrees)					
11.25	22.5	30	45	60	90
0.05	0.075	0.10	0.20	0.25	0.30
Other Fittings					
Reducer	Tee, Run	Tee, Branch	Entrance	Exit	Open Butterfly Valve
0.20	0.30	0.60	0.50	1.00	0.50

- **Outfall Facilities**
  - The discharge to the Root River via the Return Flow Pipeline will be located on Parcel 9489998001 at the southeast corner of the intersection of 60th Street and Oakwood Road in Franklin.
  - Initial Operations – Force Main / Gravity Main: The downstream end of the pipeline will discharge into a low-profile reaeration building with a slab elevation of 686.83 feet.
  - Future Operations – Force Main: A RFCB would be located upstream of the reaeration building that would serve to sustain upstream pressure to maintain a pressure pipeline.

3.4 Model Development

A steady state hydraulic model for the Return Flow Pipeline was developed using alignment data and locations of bends, valves, and fittings for the Return Flow Pipeline, exported from the Program CAD files, to determine head loss from the pre-90% progress set. Hydraulics were modeled starting from the downstream beginning at the Outfall Facilities at 1-foot interval backwater calculations. For each 1-foot interval, open-channel and pressurized hydraulics were used to calculate the head loss using the Manning's and Hazen-Williams Formulae, respectively. Hydraulics were simulated for the initial operations (as a force / gravity main) and future operations (force main).

3.5 Pipeline Size

The Return Flow Pipeline was designed for the maximum anticipated pressures, which would occur when the pipeline is operated entirely as a force main. The evaluation used C = 120 to provide a pipeline size capable of conveying the full range of heads anticipated throughout the 100-year useful life. Three pipeline nominal diameters were evaluated, including 24-, 30-, and 36-inches, based on maintaining pressures within an acceptable range up to 225 psi and at velocities of less than seven fps.

Table 3-3 summarizes maximum steady state modeled pressures and velocities observed along the pipeline for each nominal diameter.

Table 3-3 Return Flow Pipeline Sizing

Nominal Diameter (in)	Inside Diameter (in)	Velocity (fps)	Maximum Pressure (psi)
24	24.81	6.65	**294**
30	30.91	4.29	137
36	37.11	2.97	112

Notes:
1. Cells shaded **red** are greater than the maximum steady state design pressure criterion of 225 psi or the maximum velocity of seven fps.

As shown in **Table 3-3,** a 24-inch nominal diameter would result in pressures in excess of the maximum steady state design pressure of 225 psi. In consideration of the Program's vision that the Return Flow Pipeline will be designed for a 100-year useful life, a 24-inch pipeline would be insufficient. A 30-inch nominal diameter pipeline would be capable of conveying the design capacity and maximum instantaneous flow rate within acceptable pressure and velocity limits. A 36-inch nominal diameter would also sufficiently convey the demand requirements, but would result in a higher capital investment with no apparent benefit to WWU. As such, a 30-inch nominal diameter pipe is the preferred size for the Return Flow Pipeline to satisfy the demand conditions approved by the Compact Council, accommodate the RFPS firm capacity, and pursue the Program's vision for infrastructure with a 100-year useful life.

3.6 Hydraulic Grade Lines and Normal Operating Pressures

Steady state hydraulic conditions along the Return Flow Pipeline are summarized with HGLs for the purposes of defining test pressures, pressure class, and restrained joint design for both initial operations (force / gravity main) and future operations (force main) in . The HGLs are shown for 30-inch DIP for both new (C = 150, n = 0.013) and aged (C = 120, n = 0.017) conditions. The HGL for the scaled condition (C = 95) is also shown for the future operations (force main). Air Valves are shown to demonstrate which valves require low durometer seats (refer to **Section 5** for details on air valve design).

3.7 Test Pressures

Pipeline test pressures were determined in accordance with AWWA C600 Installation of Ductile Iron Pipe. AWWA C600, Section 5.2 Hydrostatic Testing recommends the test pressure to be not less than 1.25 times the stated working pressure of the pipeline measured at the highest centerline elevation and not less than 1.5 times the stated working pressure at the lowest elevation. The resulting test pressure for the Return Flow Pipeline is equivalent to an HGL of 1,060 feet. Although this pressure is sufficient for the downstream portion of the Return Flow Pipeline, it is below the anticipated HGL upstream of the hydraulic high point. For this segment, it is clear that a test pressure in excess of AWWA requirements is necessary. The test pressure for this segment has been raised to the HGL that would result under the scaled condition at the design flow rate, or a test pressure of 1,180 feet. The test pressures are shown in in **blue**.

3.8 Pressure Class

Pipeline pressure class was determined by comparing the test pressures and the isotropic pressure lines shown on . The isotropic pressure lines are shown for +150 psi (350 feet), +200 psi (460 feet), and +250 psi (580 feet) increments above the pipeline invert elevation from the pre-90% drawing progress set. The pressure classes are shown near the top of in **blue**. The Return Flow Pipeline was designed with pressure class 150 and 200 DIP and HDPE Ductile Iron Pipe Size (DIPS) Dimension Ratio (DR) 11 pipe for HDD segments.

3.9 Restrained Joints

Restrained joints were designed to balance thrust forces exerted by the flow at pipe fittings and valves in accordance with AWWA M41 and as follows. The restrained joints were value engineered for the specific depth of cover and pressure class shown in utilizing a 1.5 factor of safety and friction resistance accounting for polyethylene encasement. The unit bearing resistance, or the resistance of the soil to resist movement due to thrust forces, was conservatively neglected to account for the potential reduction in resistance due to work by others near the pipeline, such as new utilities or similar below grade construction.

3.10 Flow Velocities and Special Coatings

At velocities in excess of 15 fps, friction forces from flowing water can damage the cement-mortar lining of DIP. Unlike force mains during normal operations, gravity main segments of the Return Flow Pipeline will be driven by topography, and have the potential to excel velocities due to steep pipe slopes. Velocities along the Return Flow Pipeline were evaluated at the maximum instantaneous flow rate to identify whether any DIP sections of the pipeline would require special coatings to protect against friction forces generated from high velocities. No sections of the Return Flow Pipeline are anticipated to have velocities in excess of 15 fps during normal operation at 14.5 MGD. Thus, a special DIP coating is not required.

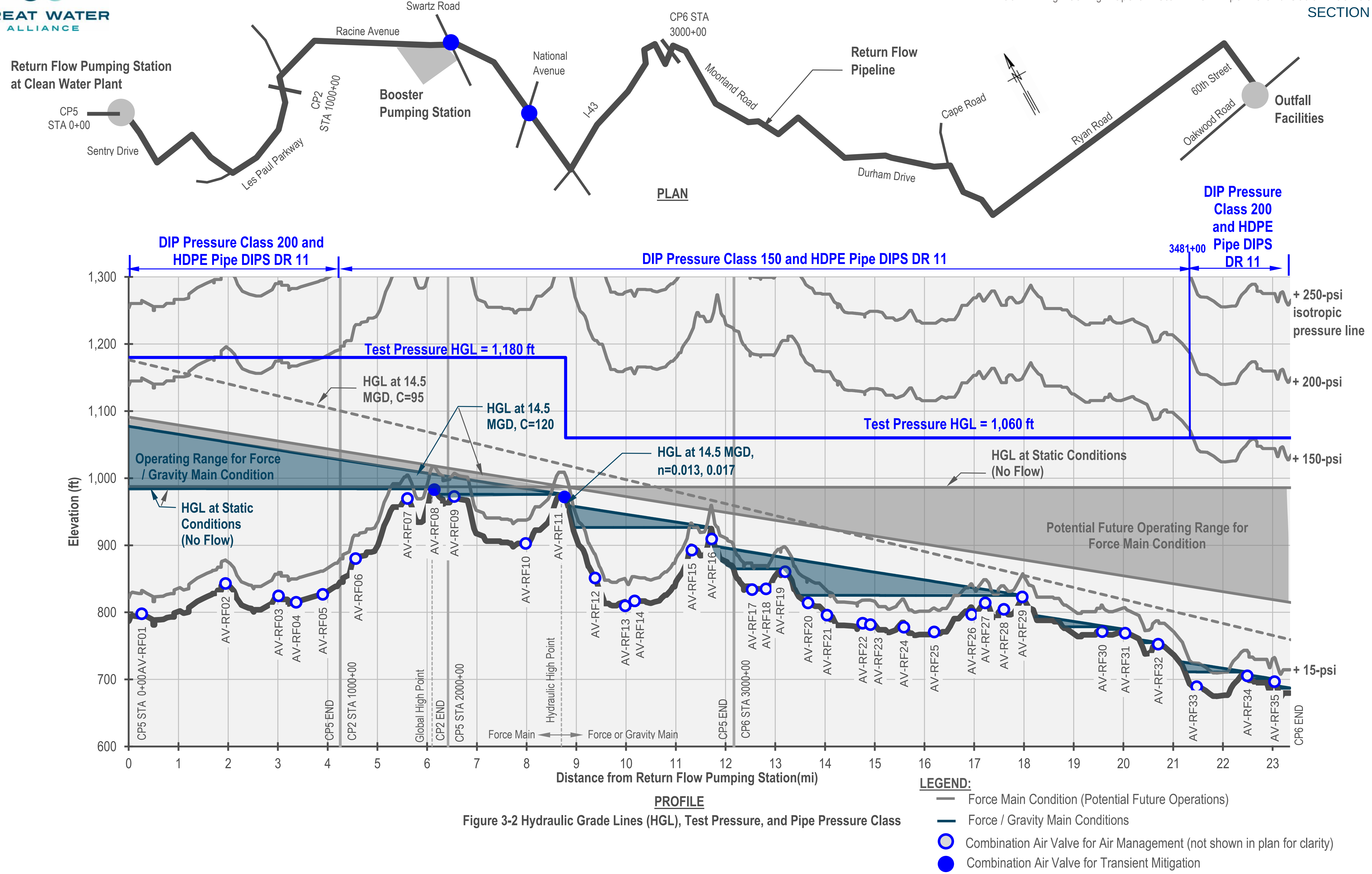


Figure 3-2 Hydraulic Grade Lines (HGL), Test Pressure, and Pipe Pressure Class

SECTION 4 Design Philosphy

The Return Flow Pipeline will be comprised of ductile iron pipe (DIP), DIP in steel casings, and high density polyethylene (HDPE) pipe along horizontal directional drilling (HDD) segments. The Return Flow Pipeline was designed to operate as both force and gravity main. The following subsections describes the approach used in designing pipe materials, horizontal and vertical alignment, construction methods, limits of construction, and operational philosophy.

4.1 Pipe Materials

Pipeline materials were evaluated, including DIP, pre-stressed concrete cylinder pipe (PCCP), steel pipe, polyvinyl chloride (PVC) pipe, and HDPE pipe. The Program determined that the pipe material for the Return Flow Pipeline will be DIP for segments constructed via open-cut construction and trenchless construction via jacking and boring. The decision was made for the following key reasons:

- WWU staff are familiar with operating and maintaining DIP.
- For the same nominal diameter, DIP has a larger inner diameter than HDPE and PVC pipe shown in **Table 4-1**. The larger inner diameter requires less head to convey flow at the RFPS.

Table 4-1 Nominal 30-inch DIP, HDPE Pipe, and PVC Pipe Geometry for 200 psi Working Pressure

DIP (inch)(1)			HDPE Pipe (inch)(3)			PVC Pipe (inch)(4)		
OD	t(2)	ID	OD	t	ID	OD	t	ID
32.00	0.51	30.98	32.00	3.08	25.83	32.00	1.62	28.77

Notes:
1. Dimensions sourced from United States Pipe and Foundry Company, TYTON JOINT Pipe.
2. Includes 0.38-inch wall thickness and 1/8-inch cement-mortar lining thickness.
3. Dimensions sourced from Performance Pipe, 4000 DIPS, DR 11 based on an average t rounded to the nearest hundredths of an inch.
4. Dimensions sourced from JM Eagle, BIG BLUE, DR 21 based on an average t rounded to the nearest hundredths of an inch.

- Quotes were received from pipe manufacturers shown in **Table 4-2**. DIP is the most economic material for the pipe diameter and rated working pressures for the Program.

Table 4-2 Material Costs For Pipe Rated for 200 psi Working Pressure

DIP(1)	HDPE Pipe(2)	PVC Pipe(3)	PCCP(4)	Steel Pipe(5)
$89/LF	$181/LF	$99/LF	$115/LF	$131/LF

Notes:
5. Quote provided by United States Pipe and Foundry Company, 30-inch nominal diameter push-on joint pipe, pressure class 200, June 2018.
6. Quote provided by Core & Main, 30-inch nominal diameter fusible joint pipe, DR 11, October 2018.
7. Quote provided by Core & Main, 30-inch nominal diameter push-on joint pipe, DR 21, October 2018.
8. Quote provided by Thompson Pipe Group, 30-inch nominal diameter push-on joint pipe, pressure class 200, January 2018.
9. Quote provided by Northwest Pipe Company, 30-inch nominal diameter push-on joint pipe, ¼-inch thickness, June 2018.

HDPE pipe was selected for use in segments of the pipeline installed with trenchless construction via HDD in areas without suspected soil or groundwater contamination. The use of DIP for HDD can damage the integrity of the polyethylene encasement typically installed with DIP, which increases the risk of corrosion and pipe failure. HDD is typically utilized where surface disruption for excavation is either not permitted or not desired for constructability reasons. Therefore, pipeline segments of DIP installed via HDD would have a higher risk of failure than the rest of the pipeline and have less means to access the pipe for maintenance and repair. HDPE pipe is jointed with smooth, heat-induced fusion welded joints that are inherently restrained and ideal for HDD applications. HDPE pipe is also inert to corrosion, reducing the risk of maintenance of repair along HDD segments than DIP.

4.2 Pipe Joints and Gaskets

Pipe joints were designed for the selected pipe materials and sizes to accommodate the pipeline and appurtenances, provide proper restraint, and allow for adequate deflection depending upon the installation condition. Push-on or mechanical joints will be provided for buried and encased DIP, and DIP in steel casings. HDPE pipe will be provided with fusion welded joints. Exposed piping in vaults will be provided with screwed joints for sizes less than three inches and flanged joints for sizes three inches and greater. Buried and exposed stainless steel vent riser pipes will be welded.

The specifications were developed to require DIP gaskets in accordance with AWWA C111 Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings. Manufacturers have indicated this requirement will lead them to provide styrene butadiene gaskets (SBR) where special gaskets are not required based on cost. Special gaskets, including Nitrile and Viton® gaskets, were specified along select pipeline reaches. Nitrile gaskets were specified at petroleum pipeline crossings owned by the West Shore Pipe Line Company in accordance with West Shore Pipe Line Company crossings requirements for 125 linear feet, centered on the crossing. In pipeline reaches with suspected soil or groundwater contamination, the type of gasket was selected based on data obtained from field investigations and as recommended by pipe manufacturers. Pipeline reaches through soil or groundwater with suspected polycyclic aromatic hydrocarbons (PAHs) were specified with Viton® gaskets through the suspected contamination and extending 50-feet beyond the suspected contamination, whereas pipeline reaches through suspected soil or groundwater contamination with no suspected PAHs were specified with Nitrile gaskets through the suspected contamination and extending 50-feet beyond the suspected contamination.

4.3 Horizontal and Vertical Alignment

The Return Flow Pipeline horizontal and vertical alignments have been developed based on the route shown in **Figure 2-4**. The plan and profiles will be submitted to WDNR as part of the 90% Contract Documents for the Program. Construction methods, including open-cut construction and trenchless construction, were utilized to develop the horizontal and vertical alignments. The construction methods described in the following subsections are based on a Return Flow Pipeline constructed of DIP with HDPE pipe used for segments requiring trenchless construction via HDD.

4.3.1 Open-Cut Construction

Open-cut construction consists of excavating a trench, laying the pipe, and backfilling the pipe to finished grade. This method requires surface restoration in the form of pavement or landscape restoration for the disturbed surface above the trench. The typical sections shown in **Figure 4-1** for open-cut construction beneath and beyond pavement were developed per applicable municipal and state standards.

It is less expensive to construct pipelines beyond pavement, as it eliminates the cost for pavement restoration. Open-cut construction beyond pavement allows the use of common fill, which is typically readily obtained from excavated spoils and less expensive than flowable or select fill required beneath pavement. The pipeline was aligned beyond pavement in each route alternative where feasible.

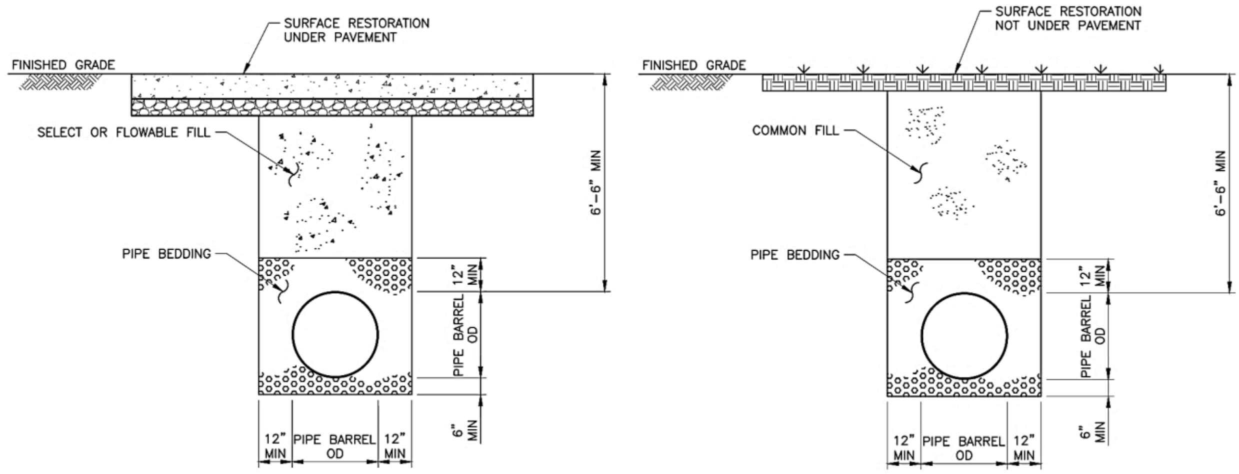


Figure 4-1 Pipeline Trench Sections Beneath and Beyond Pavement

Groundwater barriers shown in **Figure 4-2** were placed along open-cut sections of pipeline to mitigate the French drain effect that could arise due to pipe bedding and its larger porosity than that of much of the surrounding native soils. For multiple pipelines sharing a common trench, the barriers will be extended across all pipelines and keyed into native soil. Groundwater barriers were placed along the pipelines as follows:

- At intervals of approximately 1,000 linear feet along the pipeline for pipeline slopes less than 5%.
- At intervals of approximately 500 linear feet along the pipeline for pipeline slopes of greater than 5%.
- Either side of suspected soil or groundwater contamination.
- Either side of waterway crossings.

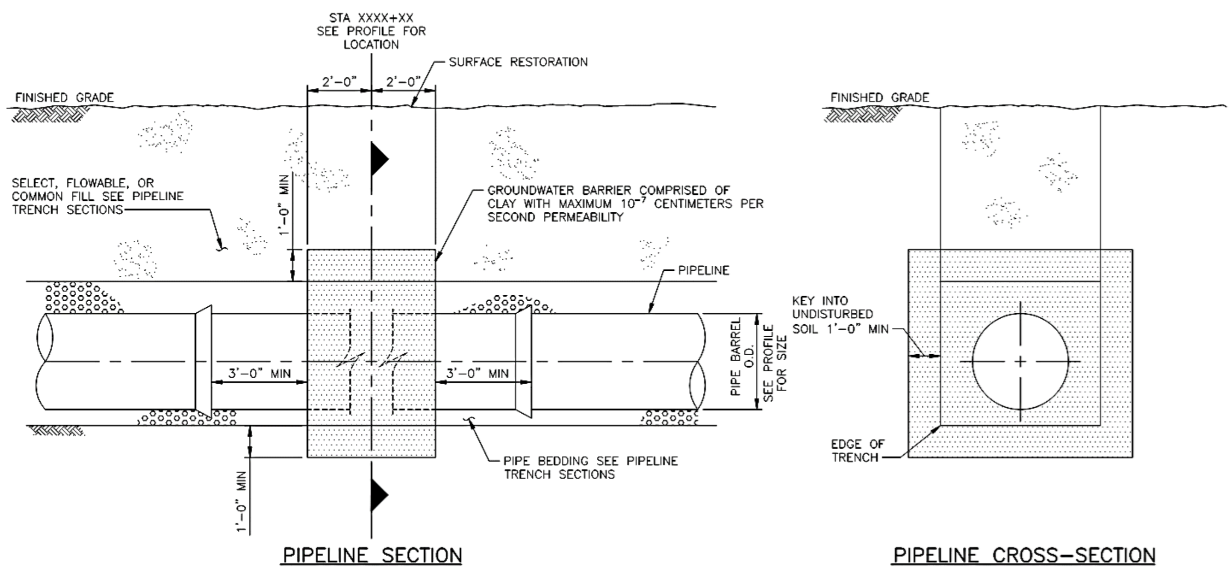


Figure 4-2 Groundwater Barrier Detail

4.3.2 Trenchless Construction

Trenchless construction is typically utilized as a means of mitigating disruption to the surface and minimizing surface restoration requirements along the length of the trenchless installation. Two trenchless construction methods have been used in design, the jack and bore and HDD methods.

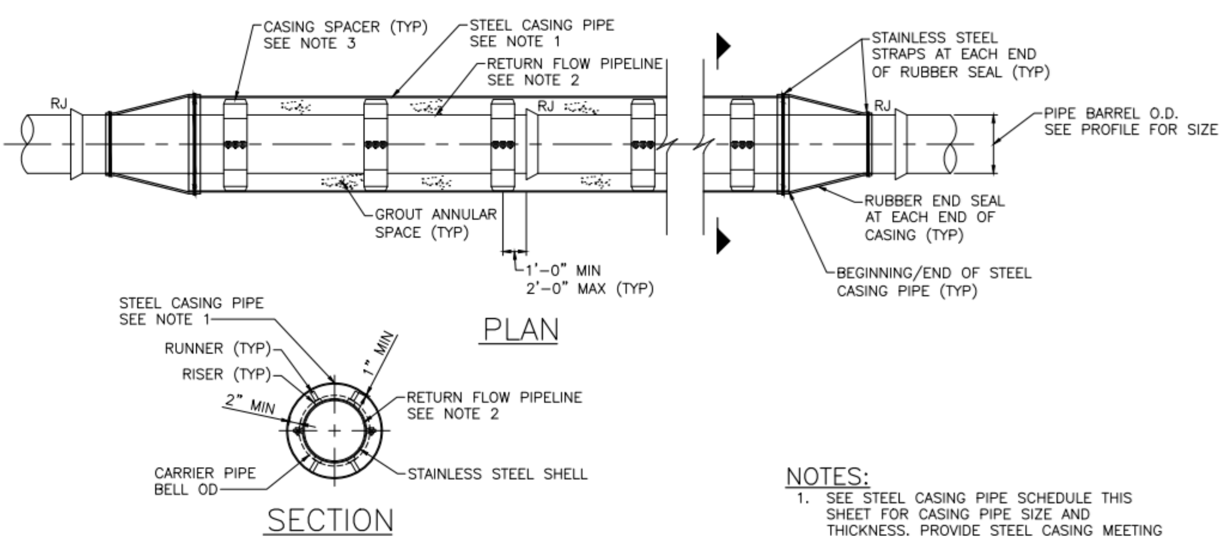
Studies have compared costs for open-cut and trenchless construction, and generally indicate that trenchless construction costs vary based on the application, locality, and diameter. Recent bid tabs in Southeast Wisconsin were reviewed to compare costs of open-cut vs trenchless construction via HDD. It was determined that trenchless construction via HDD has higher per linear foot unit cost than open-cut construction beneath pavement in the diameter range required for the pipelines for the Program on average, even when considering surface restoration for open-cut construction. In designing the pipeline, open-cut construction was utilized where feasible. Trenchless construction was considered to mitigate the following:

- Impacts to waterways crossing route alternatives.
- Traffic disruption where the pipeline is anticipated to be located under major roads, highways, and railroads.

The Program worked with the WDNR in preparation for the Wetland and Waterway Impact Permit Application submitted to WDNR in June 2019. A practicable alternatives analysis was used to demonstrate the required minimization of wetland impacts. Trenchless construction was not considered a practicable alternative to avoid temporary impacts to wetlands due to the higher cost required for the construction method.

4.3.2.1 Jack and Bore Method

The pipeline has been designed using the jack and bore method to cross railroad tracks or as a means to mitigate traffic disruption when crossing a major roadway. A plan and section view of the pipeline installed via jacking and boring is shown in **Figure 4-3**. Jack and bored crossings can typically be installed up to 400 feet in length.



STEEL CASING PIPE SCHEDULE			
RETURN FLOW PIPELINE NOMINAL DIAMETER	STEEL CASING PIPE INSIDE DIAMETER	STEEL WALL THICKNESS	
		ROAD	RAIL
30"	48"	0.625"	0.688"

NOTES:
1. SEE STEEL CASING PIPE SCHEDULE THIS SHEET FOR CASING PIPE SIZE AND THICKNESS. PROVIDE STEEL CASING MEETING THE REQUIREMENTS OF ASTM A139, GRADE B.
2. PROVIDE CARRIER PIPE WITH RESTRAINED JOINTS (RJ) THROUGHOUT THE LENGTH OF THE STEEL CASING PIPE.
3. INSTALL CASING SPACERS OVER POLYETHYLENE ENCASEMENT AND TRACER WIRE. POLYETHYLENE ENCASEMENT AND TRACER WIRE NOT SHOWN FOR CLARITY.

Figure 4-3 Trenchless Construction via Jack and Bore Method

The steel casing diameter required to accommodate the Return Flow Pipeline is larger than the diameter range and thickness requirements provided by many authorities having jurisdiction where the Return Flow Pipeline will be located. As such, the thickness of the steel casing was calculated in accordance with American Water Works Association (AWWA) M11 using the Iowa deflection formula for bare pipe with a deflection factor of 5.0%, a modulus of elasticity of 30,000,000 psi, a bedding constant of 0.1, a deflection lag factor of 1.0, and soil loads and live rail and road loads in accordance with AWWA M11. The modulus of soil reaction was conservatively neglected to account for future work done by others near the pipeline, such as new utilities or similar below grade construction, which could sacrifice the soil's structural integrity. The annular space between the pipeline and casing pipe will be grouted in order to mitigate potential groundwater infiltration that could result in corrosion of the pipeline.

4.3.2.2 Horizontal Directional Drilling (HDD)

HDD was used for longer trenchless installations beyond that of the jack and bore method, such as that required for waterway crossings. The Return Flow Pipeline design was developed to include construction via HDD comprised of 36-inch HDPE DIPS DR 11 pipe. Transitions to HDD will be accomplished as shown in **Figure 4-4**. The larger HDPE pipe diameter was used to accommodate HDPE pipe's wall thickness required to accommodate pipeline pressures, thereby maintaining a comparable inner diameter to the DIP. The radius of curvature for HDD segments was designed to account for the limiting radius of curvature of drilling equipment based on feedback from HDD contractors.

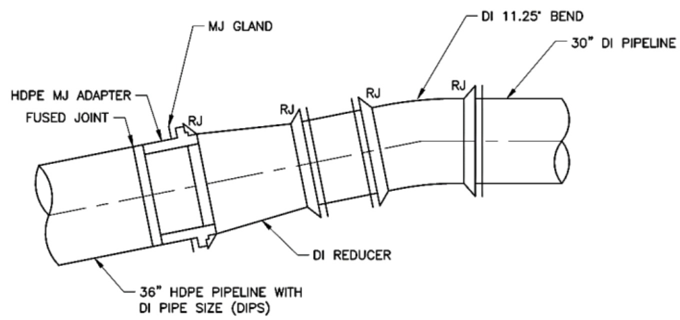


Figure 4-4 DIP to HDPE Pipe Transition

4.3.3 Minimum Horizontal Separation

The Return Flow Pipeline will be located in the same corridor as the BPS Discharge Pipeline for approximately two miles of the alignment and within the same corridors as existing water main at various locations along the pipeline. Existing utilities were surveyed and overlaid upon the plan and profile sheets during design. Discussions with the WDNR have indicated the WDNR will classify the Return Flow Pipeline as a sanitary sewer force main. The Wisconsin Administration Code, NR 811.74, requires sanitary sewer main to be laid a minimum of eight-feet horizontally, center to center, or a minimum of three-feet horizontally, wall to wall, from any existing or proposed water main. The horizontal alignment has been developed to satisfy this requirement.

4.4 Limits of Construction

4.4.1 Open-Cut Construction

The limits of open-cut construction were quantified to provide a basis for maintenance of traffic requirements and to design limits of construction on the drawings. The limits of open-cut construction for a single pipeline are anticipated to be a maximum of 50-feet wide as described below and as shown in **Figure 4-5**:

- Two-foot wide traffic barrels and a two-foot width between the traffic barrels and dump truck.
- A 10-foot wide dump truck.
- A 12-foot wide excavator above the pipe trench with four-feet on either side to account for tail swing.
- A 10-foot wide staging area for materials.
- Two, 3-feet wide workspace buffers to the limits of construction.

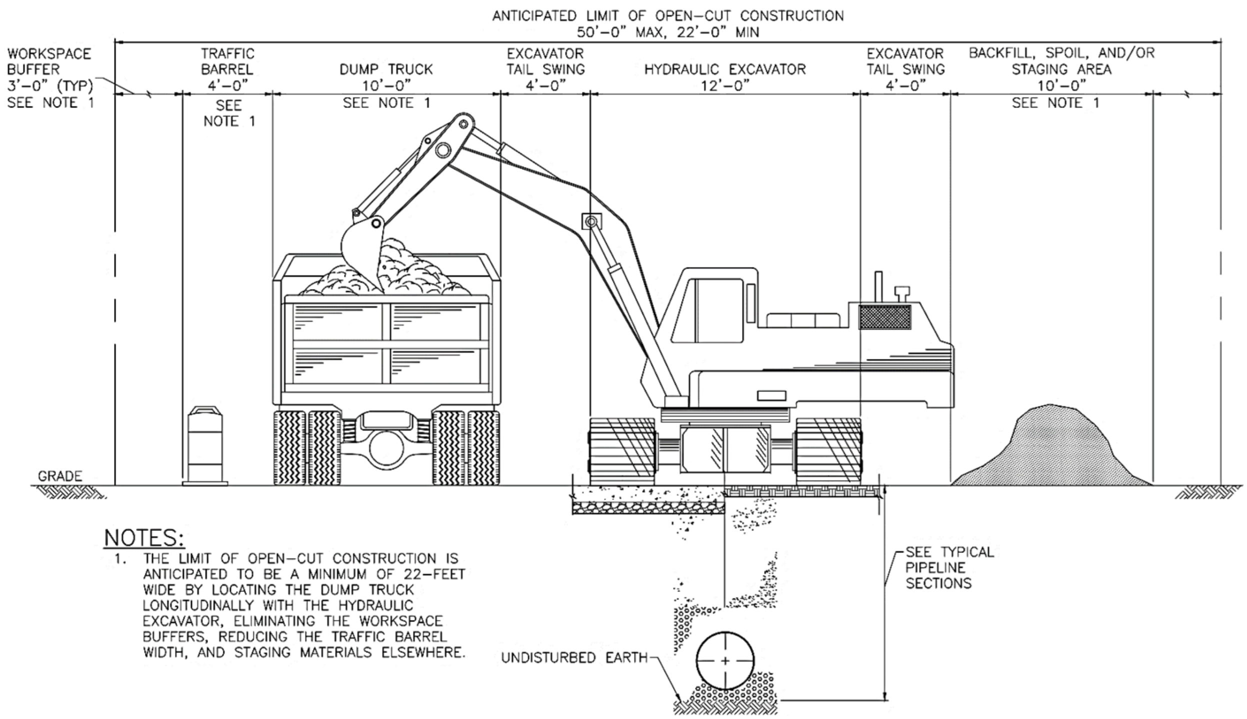


Figure 4-5 Anticipated Limits of Open-Cut Construction

In select areas, the minimum limits of construction for a single pipeline will be set at a minimum of 22-feet wide. The contractor will locate the dump truck longitudinally with the excavator, eliminate the workspace buffers and reduce the traffic barrel width, and stage materials elsewhere. It is anticipated the limits of construction will be larger than the minimum width of 22-feet where pipeline appurtenances are required, such as blow-off assemblies, air valves, and isolation valves. The limits of construction will be increased where the BPS Discharge and Return Flow Pipelines are located in the same corridor and utilize open-cut construction.

Note that the contract documents include the limits of construction, not the staging of specific equipment. The contractors will have the autonomy to setup equipment in a manner so as to efficiently and effectively complete the work. The contractor may elect to stage in a different manner than that shown in this Report.

4.4.2 Trenchless Construction

If space within the right-of-way permits, then equipment, pits, and materials used for trenchless construction via the jack and bore method could be staged beyond pavement to reduce maintenance of traffic requirements. If space within the right-of-way beyond pavement is limited, then limits of trenchless construction via the jack and bore method are anticipated to utilize the 22-foot width of a two-lane, two-way road assuming the following equipment and material are staged behind the pits:

- Two-foot wide traffic barrels.
- 20-foot wide working and receiving pits. The jacking pits have been shown on the drawings to assist the contractor in staging during construction.

If space within the right-of-way permits, equipment and materials used for trenchless construction via HDD can be staged beyond pavement to reduce maintenance of traffic requirements. If space within the right-of-way beyond pavement is limited, then the limits of HDD construction for a single pipeline are anticipated to utilize the 22-foot width of a two-lane, two-way road assuming the following as shown in **Figure 4-6**:

- Two-foot wide traffic barrels and a two-foot width between the traffic barrels and HDD rig.
- An eight-foot wide HDD rig.
- A 10-foot wide staging area for materials and equipment supporting HDD operations.

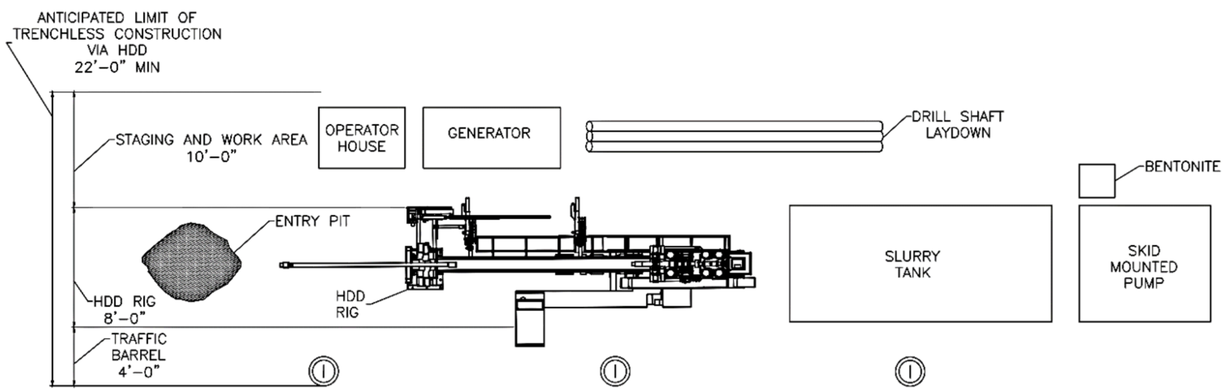


Figure 4-6 Anticipated Limits of Trenchless Construction via HDD

Potential for substantial reduction of the trenchless construction width down to one lane of traffic is limited for the following reasons:

- It is desirable to stage the operator house adjacent to the entry pit so the drilling can be safely observed.
- Additional space is required where pipeline appurtenances are located, such as blow-off assemblies, air valves, and isolation valves that require manholes. Blow-off assemblies and air valves will require outlets routed to the right-of-way beyond pavement.

Workspace for HDD construction is required simultaneously on both ends of the trenchless segment. When using HDPE pipe, the pipe joints are typically heat-fused at the surface and strung out for the length of the intended trenchless segment beyond the exit point of the trenchless segment. The specifications were developed to allow the contractor the ability to heat fuse only segments of a given portion of an HDD segment if space constraints exist in the right-of-way.

4.5 Topography, Operation, and Control

The Return Flow Pipeline is required to convey flow across the subcontinental divide to provide a net zero water balance in the Great Lakes–St. Lawrence River Basin. The subcontinental divide serves as a global high point along the Return Flow Pipeline. A hydraulic high point also exists east of the subcontinental divide where the pipeline could transition to gravity-driven flow. The RFPS will provide the head necessary upstream of the hydraulic high point to convey flow into the Great Lakes–St. Lawrence River Basin. Along this upstream segment, the Return Flow Pipeline will be operated as a force main. The portion of the Return Flow Pipeline downstream of the hydraulic high point could be operated as either a force main or gravity main. The two operational alternatives were compared to determine the most cost-effective solution. The alternatives are described below and shown in **Figure 4-7** and **Figure 4-8.**

- **Force Main:** The elevation difference between the hydraulic high point and the discharge elevation to the Root River is greater than the head required to convey the flow. Operating the Return Flow Pipeline as a force main would allow the potential for energy recovery of the remaining static head available with hydroelectric turbines and to provide additional head to route flow to users in the Great Lakes–St. Lawrence River Basin, thereby allowing for water reuse in the future. In order to operate the Return Flow Pipeline as a force main, control valves located at the Outfall Facilities would be required to supplement the head loss induced by the hydroelectric turbines and sustain pressures in the Return Flow Pipeline downstream of the hydraulic high point. The control valves and turbines would be located in an above grade structure, referred to as the Return Flow Control Building (RFCB) at the Outfall Facilities.

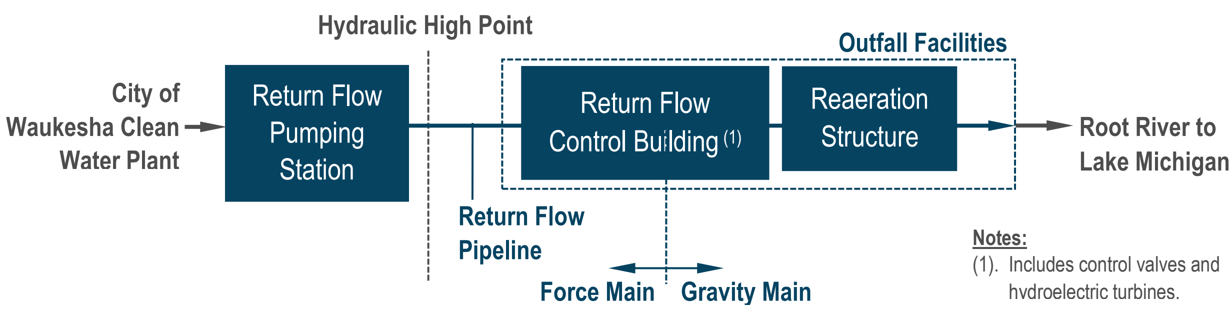


Figure 4-7 Return Flow Pipeline Operated as a Force Main

- **Force / Gravity Main:** Operating the Return Flow Pipeline as a gravity main downstream of the hydraulic high point would not require the RFCB. The operational configuration would preclude energy recovery and water reuse.

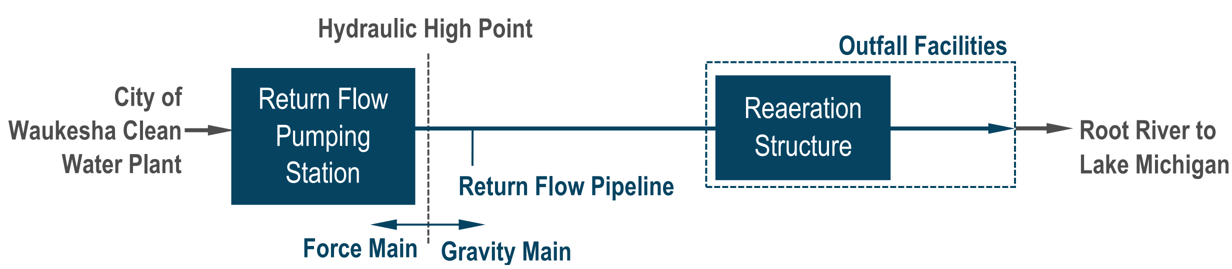


Figure 4-8 Return Flow Pipeline Operated as a Force / Gravity Main

An evaluation for recovering energy was conducted to confirm economic justification of the preferred operational scheme. Based on current energy pricing, energy recovery was determined to not be a cost-effective solution. Based on the results of this energy evaluation and the increased capital, operation and maintenance costs associated with the RFCB, it was recommended to proceed with operating the Return Flow Pipeline as a force / gravity main. Per discussions with WWU, the Return Flow Pipeline will be designed so as to have the capability of being operated entirely as a force main in the future.

4.6 Pipeline Appurtenances

Pipeline appurtenances were designed for the Return Flow Pipeline to provide for ease of maintenance and air management. Key design philosophies for each appurtenance are described in the following subsection.

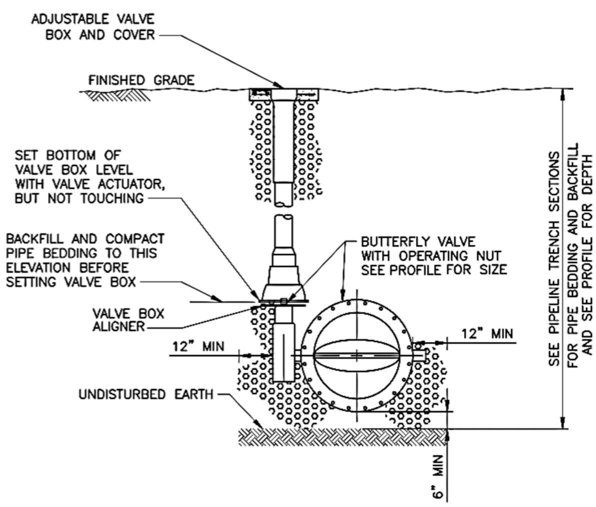
4.6.1 Isolation Valves

Four types of isolation valves were considered for the pipeline, including butterfly, gate, ball, and plug valves. Ball valves are not generally utilized for isolation valves on water transmission mains and are typically more expensive than gate valves. Plug valves are commonly used in the wastewater industry, but are more expensive than gate valves. Based on the economics, suitability for the application, and product availability, ball and plug valves were determined to be less preferable and were not further evaluated as means of providing isolation for the pipeline.

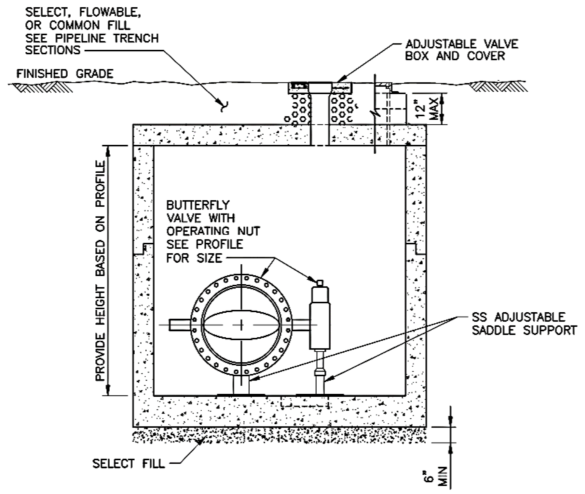
Butterfly valves and gate valves were further evaluated. Butterfly valves are lighter in weight, more compact in size, require lower operating torque, and are less costly than gate valves. However, gate valves do not have a disc that passes through the flow path and, therefore, induces a lower head loss during operations. A lifecycle cost evaluation was completed and it was determined the monetary savings from lower head loss would not compensate for the higher capital cost of the gate valve. Based on economic and non-economic considerations, it was determined that butterfly valves will be used as a means of isolation for the pipeline.

Isolation valves can be installed in vaults or direct buried with a valve box for the valve operator. Installation of vaults allows for ease of maintenance, but would be susceptible to groundwater infiltration. Direct buried valves with valve boxes are more cost-effective and are more common for water utilities, but maintenance would require excavation. Isolation valve details were reviewed with WWU. It was determined that isolation valves will be direct buried to reduce capital cost and additional maintenance associated with vaults. Isolation valves in vaults were designed upstream of surface water crossings greater than 15 feet in width in accordance with NR 811.76. Sections of the isolation valve details developed for the pipeline are shown in **Figure 4-9.**

In coordination with WisDOT and FHWA, a pressure gauge and transmitter has been added to one of the isolation valve vaults in proximity to the I-43 right-of-way. In the event of pipeline breakage, an alarm will be communicated to the RFPS. Pumping would then be stopped, and the break would be repaired.



Section, Buried



Section, In Vault

Figure 4-9 Isolation Valve Details

4.6.2 Blow-Off Assemblies

Pipelines require appurtenances that will provide means to drain the pipeline during startup, routine maintenance, or repairs. Two types of appurtenances were evaluated for draining the pipeline, including blow-off assemblies and flushing hydrants. Blow-off assemblies are typically used for transmission mains as they reduce the potential for unintended use by eliminating above grade components, whereas flushing hydrants, which are commonly used for distribution systems, include a hydrant above grade.

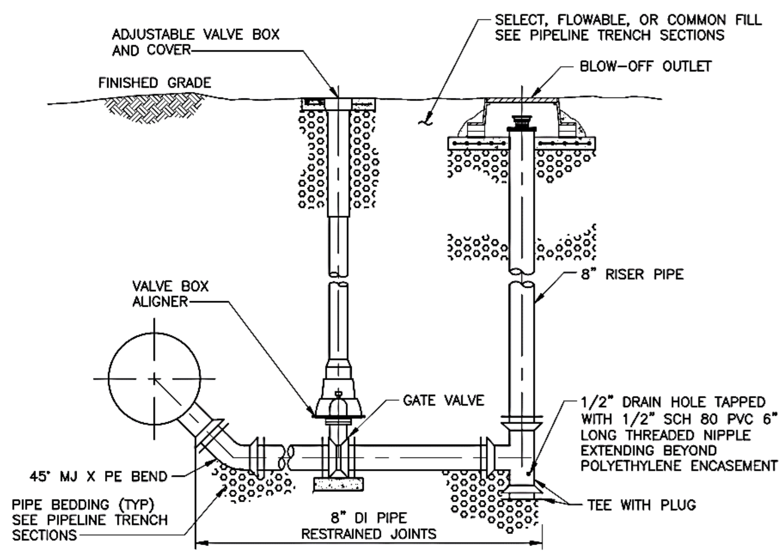


Figure 4-10 Blow-Off Assembly Detail – Section

Flushing alternatives were reviewed with WWU and it was determined that blow-off assemblies are preferred as it limits the potential for access by outside entities in the communities that the pipeline will be located. Blow-off assembly details developed for the pipeline are shown in **Figure 4-10**.

4.6.3 Air Valves and Pipeline Access

Hydraulic transients can lead to vacuum conditions that require air to be admitted into the pipeline to protect against pipeline breakage. Air entrainment can reduce pipeline capacity, which can lead to lower pumping efficiency and, potentially, air binding of the system. In order to minimize the rise and fall of the pipeline elevations, which could result in additional air valves, the pipeline may need to be buried deeper. This increases the cost of installation through additional cut and fill, but can eliminate the need for additional air valves. The vertical alignment was optimized to balance cut and fill with additional air valves. Air valves were located along the resulting vertical alignment at local high points. The release of dissolved oxygen from the highly treated effluent along the Return Flow Pipeline is not readily quantifiable. To provide for air management, the pipeline was designed with provisions for automatic air release at local high points. Refer to **Section 5** for the method used in sizing the air valves, air valve details, and the size, type, and location of air valves.

4.7 Corrosion Control and Cathodic Protection

Corrosion is a common mechanism that can reduce the service life of any metallic pipe, including DIP. The Return Flow Pipeline was designed per AWWA standards. Design provisions in excess of AWWA standards were included to provide for a 100-year service life to mitigate the potential for corrosion as follows:

- **Polyethylene Encasement:** AWWA C105 Polyethylene Encasement for Ductile-Iron Pipe Systems requires a single layer of polyethylene encasement to mitigate soil and groundwater-induced corrosion. The Return Flow Pipeline was designed with two layers of polyethylene encasement. The inner layer will consist of V-Bio® Enhanced Polyethylene Encasement, which includes a layer to mitigate biologically-induced corrosion from any soil or groundwater that could have migrated into the annular space between the pipe wall and the encasement during installation. The outer layer will consist of standard polyethylene encasement in accordance with AWWA C105. After installation, both layers will serve to mitigate soil and groundwater-induced corrosion by preventing migration of soil or groundwater to the pipe wall.
- **Galvanic Magnesium Anodes:** The Return Flow Pipeline was designed with buried sacrificial galvanic magnesium anodes based on findings from field investigations from soil borings and coordination with existing utilities that utilize cathodic protection. In the presence of a corrosion mechanisms, magnesium corrodes preferentially to iron. Should the two layers of polyethylene encasement become locally compromised, the magnesium anodes will corrode preferentially to the DIP. Sacrificial anodes are not required per AWWA standards. A trench section at a galvanic magnesium anode developed for the pipeline is shown in **Figure 4-11**.

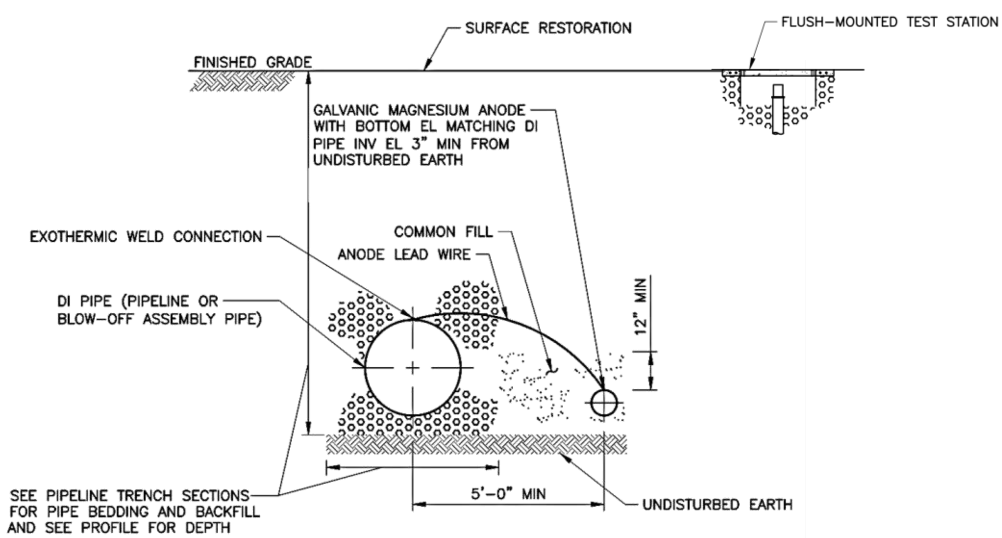


Figure 4-11 Trench Section at Galvanic Magnesium Anode and Test Station

- **Bonded Joints and Test Stations:** The Return Flow Pipeline will be installed with test stations as shown in **Figure 4-11** and bonded DIP joints as shown in **Figure 4-12**. The test stations will be provided along the pipeline, at the ends of steel casings, and at utility crossings. The test stations will be used during the life of the pipeline to monitor for corrosion. If any readings demonstrate corrosive signatures, the pipeline would be uncovered and inspected, and efforts implemented to mitigate corrosion. Bonded joints and test stations are not required per AWWA standards. Pipeline electrical isolation pieces shown in **Figure 4-12** were provided at contract package breaks and ends of the pipeline in order to protect the pipelines for corrosion induced from connections to adjacent existing or new infrastructure.

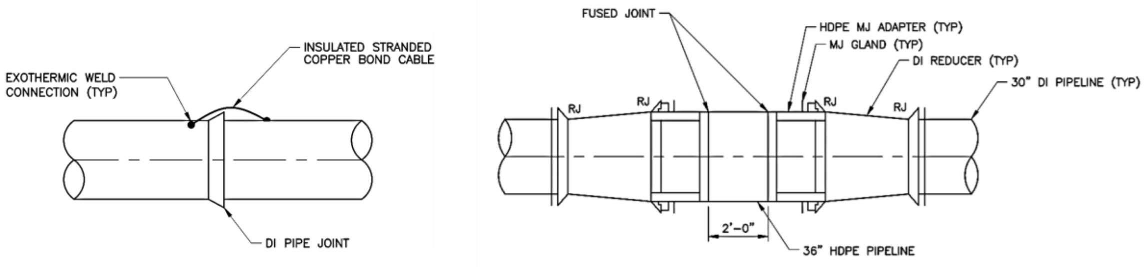


Figure 4-12 Bonded Joints and Electrical Isolation Detail

SECTION 5 Transient Hydraulics and Air Management

Transient mitigation devices in the form of pump discharge transient control valves, surge relief valves, air valves or surge tanks are required to mitigate hydraulic transients. Air management appurtenances are also needed to a) maintain capacity during normal operation by releasing entrained air and b) provide for smooth operations during the filling and emptying of the pipeline. To achieve these goals, devices of appropriate type and size were designed at strategic locations. Results from more than one methodology were synthesized. In the following sections, such methods are detailed after the development of the transient hydraulic model is described.

5.1 Transient Hydraulics

5.1.1 Model Software and Capabilities

Hydraulic transients refer to flow phenomena that occur in between steady state conditions. Although gradual flow transitions also fall into the category, the focus is on changes that take place over short time periods. The impact of these abrupt changes in a fluid's momentum can be conveyed to parts of the system located several thousands of feet to miles away from the source. It is this combination of short time periods and the large scale of the pipelines that makes hydraulic transients challenging both to measure in the field and to model numerically.

Focusing on the latter method of analysis, the goal is twofold: to develop models of low "simulation cost" solutions that are also capable of capturing the physics of the phenomenon. The Method of Characteristics is a numerical analysis technique with a proven record of achieving this goal. The technique has been successfully applied to analyze a variety of engineering problems that defied analytical solutions. Since its first commercial implementation within the software engine of Liquid Transients (LIQT), the Method of Characteristics has been used extensively in the study of transient flows in pressurized pipeline systems. As with any method of numerical analysis, transient analyses based on the Method of Characteristics comes with specific limitations and assumptions. These assumptions should always be considered when one evaluates LIQT model results and are summarized as follows:

- Flow in pipes is one-dimensional.
- The velocity distribution is uniform throughout a pipe cross-section.
- The system is always primed (i.e. open-channel transients cannot be resolved).
- Both fluid and the pipe material are elastic (i.e. relationship of stress-strain is linear).
- Friction losses during transient events can be approximated using steady state flow formulae.

5.1.2 Model Development

The development of the RFPS and Return Flow Pipeline transient model in LIQT followed standard modeling procedures (DNV GL, 2018a and 2018b). Sources of information to build the model were from the pre-90% progress drawing set and preliminary engineering documentation available at the time the study was carried out. For elements of the system lacking such information, the parameterization was performed upon close coordination with the design team, application of engineering judgement, and execution of sensitivity model runs.

5.1.2.1 Return Flow Pumping Station (RFPS)

The four pumps designed for the RFPS were explicitly modeled in a parallel configuration with four respective lines. Each pump discharge line was equipped with a check valve, which was modeled for fast closure at the onset of reverse flow. Minor head losses due to fittings, instrumentation, and appurtenances were modeled with a lumpedsum coefficient (K-factor) applied on each pump line. K factors were identical to those used for the steady state hydraulic analysis.

The RFPS pumps are equipped with variable speed drive units. These allow for a controlled (slow) starting process, which effectively mitigates the risk of startup-induced transients. The LIQT software's embedded capabilities to model the variable speed pump operation were used. The pump performance data utilized was based on manufacturers' pump curves for flow and head required. Pump specific speeds and torques were calculated and imported into LIQT. Through this information, the LIQT model was able to generate pump characteristics in all four quadrants of operation based on built-in libraries of dimensionless head-flow and torque-flow curves. This is an important step for the accurate simulation of the pumps' behavior in the wake of a power outage.

The RFPS wet-well was modeled as a node having a fixed hydraulic head at elevation 796.8 feet based on results from preliminary simulations demonstrating that high suction head results in increased transient impact.

5.1.2.2 Return Flow Pipeline

Opportunities to reduce the size of the model through skeletonization of its elements were leveraged to a relatively small extent, as emphasis was placed on model accuracy. Both DIP and HDPE pipe segments of the pipeline longer than 20 feet were modeled explicitly. Due to LIQT's limitation in modeling pipe curvature, each HDPE pipe segment was approximated with three components: two sloped segments and one horizontal segment. Other geometrical and material properties (wall thickness, Young's modulus, Poisson ratio) were obtained from standard industry publications and textbooks (Beieler, 2012; Nayyar, 1992). Acoustic wavespeeds for each pipe material were estimated using LIQT's internal calculator as 3,620 fps for DIP and 1,133 fps for HDPE pipe.

The model was set up to calculate frictional pressure drop using C=150. This coefficient was adjusted for pipe segments including fittings and appurtenances to account for the minor head losses introduced.

At the downstream end of the Return Flow Pipeline, a constant pressure boundary, translated into an HGL of 870.4 feet, was used. This number was obtained iteratively, until a buffer of 5 psi between the HGL and the pipeline at the system's hydraulic high point where transition to gravity flow with open channel segments occurs.

5.1.2.3 Appurtenances

5.1.2.3.1 Flow Control Valves

Isolation valves, which will physically exist in the system, but remain open during normal and transient flow conditions are not significant to the analysis and, therefore, were not modeled explicitly. The minor head losses introduced by such valves were incorporated for the appropriate pipe segment.

5.1.2.3.2 Air Control Valves

Air valve assemblies were added to the model to mitigate the transient impact. The parameterization of these assemblies did not follow a specific air valve model. Instead, a conservative assumption for the discharge coefficient was made (C_d=0.65) so that a wide range of options would remain available for the selection of the actual air valve devices. The boundary conditions at the atmospheric side of the air valves were modeled as fixed hydraulic head equal to the elevation at the top of the valves. Critical assumptions for attaining levels of air valve performance as described by model outputs include:

- The air valves will be mounted directly on top of the pipeline's crown.
- The vaults housing air valves are positioned as close as possible to locations where pipe changes slope (high points, beginning or end of horizontal pipe runs).

5.1.2.3.3 Surge Tank

Simulations demonstrated the use of a surge tank would effectively mitigate a portion of the hydraulic transients. In the absence of design drawings or specifications for such a device, its parameterization was initially performed using peer-reviewed documentation (Stephenson, 2002). Subsequently, parameters were fine-tuned based on the suggestions of the design team for the RFPS and results from exploratory simulations.

The final configuration included a closed surge tank (i.e. air chamber containing liquid and gas under pressure). The modeled surge tank was equipped with a check valve at the bottom, allowing for one-way relief of the containing liquid during a transient event.

A polytropic exponent of 1.4 was selected to model the thermodynamic processes of gas expansion/compression as isentropic (not allowing transfer of heat). The initial volume of gas in the tank was selected equal to 825 cubic feet. The roughness of the piping connecting the tank to the pipeline through a single inlet/outlet was modeled with C=150.

5.1.2.4 Fluid Properties

The fluid properties applicable to this transient modeling effort are included in **Table 5-1** below.

Table 5-1 Fluid Properties used in LIQT Simulations for the Return Flow Pipeline System

Property	Value	Unit
Temperature	60	Degrees Fahrenheit
Specific Gravity	1.0	dimensionless
Bulk Modulus of Elasticity	308,000	psi
Kinematic Viscosity	1.3×10^{-5}	ft^2/s
Vapor Pressure Head	0.5	psig

The entire return flow system is assumed to behave isothermally (i.e. filled with liquid at constant temperature). Furthermore, it was conservatively assumed that the liquid column is devoid of free air at the beginning of each model run.

5.1.2.5 Initial Conditions, Time Step, and End of Simulations

To prevent spurious outputs due to "warm-up" effects, the model was allowed to run for 20 seconds under steady state conditions prior to introducing a transient-inducing event.

A diminutive, 3-millisecond computation time step was used to facilitate convergence of the solution and to ensure that the fast-evolving phenomenon is adequately captured throughout the computational domain.

Several trial runs were performed prior to setting 300 seconds as the appropriate end point for the simulations, beyond which new information does not have a practical impact on the conclusions.

5.1.3 Sensitivity Analyses

Once the LIQT model had been built, a number of simulations were performed to establish confidence in the selection of model parameters. For example, the liquid's physical characteristics (specific gravity, viscosity, temperature, and vapor pressure) were varied within realistic ranges and found to have negligible impacts on the model's output. Similar findings were reported for parameters related to environmental conditions, such as ambient temperature and barometric pressure.

Another round of model runs was completed to determine the transient impact as a function of targeted system characteristics. These runs ultimately demonstrated that the combination of high suction head and low pipe roughness constitutes the worst-case scenario for the transient evaluation and sizing of transient mitigation devices.

As far as the performance of transient mitigation devices is concerned, the way air valves are connected to the pipeline was initially evaluated. It was found that the effectiveness of the device is reduced the farther from the crown of the pipe it is connected. Furthermore, the lower the slope of the connecting pipe, the worse the protection against transients became.

Regarding the surge tank, numerous simulations were performed to test the impact of the thermodynamic process (through the selection of the polytropic exponent), the initial volume of gas, and the geometry (total length and diameter)/configuration (dual versus single inlet/outlet) of the connecting piping. Knowledge from these runs assisted with the judicious selection of parameters and furnished a better understanding about the degree of conservatism that was built into the final model runs.

5.1.4 Baseline (Unmitigated) Transient Impact Scenario

The LIQT model was used in basis of discovery simulations to better understand the system's response to transient-inducing events. The ultimate goal was to define the maximum probable transient impact. This would, subsequently, serve as the baseline to evaluate the effectiveness of transient countermeasures. The simulations identified the case of simultaneous pump failure (power outage) as the critical scenario. Such result was in agreement with past experience of the modeling team and with published studies of similar pump and pipeline systems (Islam et al., 2014; Stubblefield et al., 2014).

To obtain the maximum probable transient impact, the pumps were operated at 14.5 MGD. The suction head at the pumps was at its maximum level and C=150 was utilized. No special protocols for flow control were implemented, other than programming the check valves installed at each pump to close in less than a second, when reverse flow becomes imminent. Downstream boundary conditions provided pressurized flow throughout the pipeline, which maximized the transient impact.

The instantaneous transient HGL envelope summarizes the vast amount of outputs from a transient simulation, as shown in **Figure 5-1** for the baseline (unmitigated) transient impact scenario.

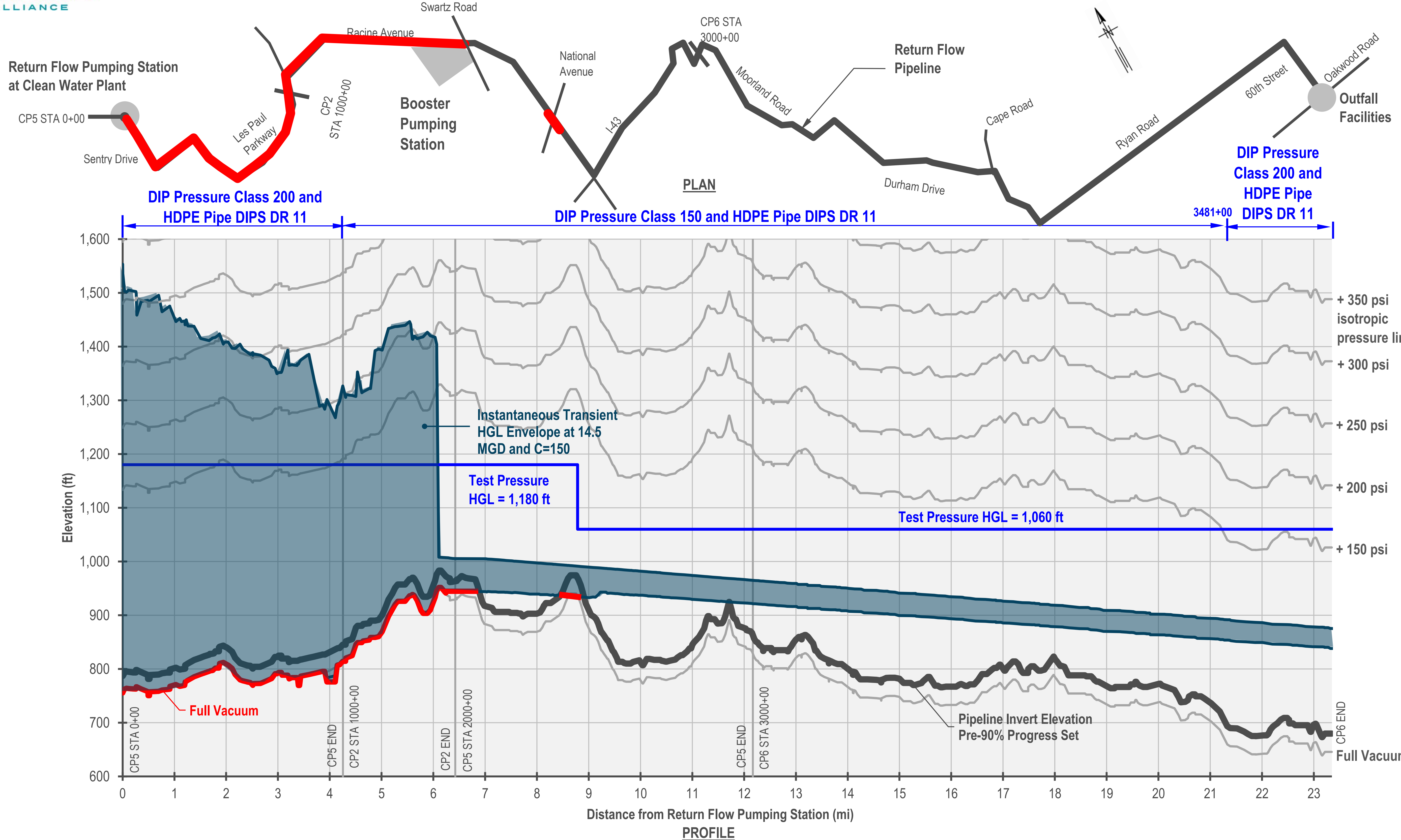


Figure 5-1 Unmitigated Instantaneous Transient HGL Envelop

As shown in **Figure 5-1**, substantial deviation from the steady state HGL was observed for the upstream segments of the pipeline. Specifically, positive pressure spikes exceed 250 psi with the maximum value recorded at the RFPS discharge node. Negative pressures, all the way down to full-vacuum, were consistently reached at pipeline sections from the RFPS to the global high point. The development of an ever-growing vapor cavity at the global high point acted as a reflective boundary, hence allowing only partial propagation of the negative waves to the downstream pipeline sections. Based on this finding, a vacuum breaking device and/or a surge tank would be good candidates for the mitigation of this type of transient impact.

Shortly after the power failed, pressures dropped at sub-atmospheric levels and eventually down to full vacuum. This wave of negative pressures is the so-called *downsurge*. Negative pressures act as radial forces that introduce additional compressive stress on the pipe wall, increasing the risks of structural deformation at the pipe joints and pipe failure by implosion. Another direct consequence of downsurges is the formation of vapor cavities. These cavities form a discontinuity in the fluid's column – a phenomenon known as liquid column separation. In liquid column separation, the water column breaks into two parts (one upstream and the other just downstream of the cavity), which begin to move within the pipeline independently of one another. This growth phase of the cavity could be temporarily interrupted when the separated columns rejoin later in the evolution of the transient event. The collision is violent (slam). It culminates with a positive pressure spike in the time series, which is defined as *upsurge*. Episodes of alternating downsurges and upsurges repeat quasi-periodically and with varying intensities. Eventually, the magnitude of the peaks diminishes with time due to the dissipation of energy to heat by friction.

Using the knowledge about the transient impact on the return flow system, the next step of the study is to establish quantitative and objective criteria to provide effective mitigation.

The transient impact from pressure upsurges is well studied and documented. It is incorporated in the design of pipelines through the metric of the maximum allowable surge pressure. DIP and HDPE DIPS DR 11 pipe is furnished with 100 psi allowance for surge. The nominal maximum allowable surge pressures for the pipeline pressure classes are as follows: (note that throughout the baseline simulation, the maximum allowable surge pressures were exceeded at multiple locations)

- **DIP Pressure Class 200:** 300 psi.
- **HDPE Pipe DR 11:** 300 psi.
- **DIP Pressure Class 150:** 250 psi.

On the other hand, the documented impact of pressure downsurges (Autrique et al, 2016, Fleming et al, 2006, Ivetic 2004) has yet to be translated into a practical guideline. There is limited mention in industry standards or the literature of a metric along the lines of a minimum allowable surge pressure. Research of the literature was complemented by direct communication with industry groups, such as the DIPRA.

The major findings of these efforts are summarized in the following items:

- There is a lack of understanding on the impact that varying vacuum durations and repeating vacuum episodes (cyclic loading/fatigue) have on the structural integrity of DIP.
- Push-on joint DIP can withstand negative pressures up to -14 psi (which is close, but not equal to full-vacuum) without structural deformation, such as buckling.
- HDPE pipe can withstand greater negative pressures that DIP.

- Limited information or guidance is available regarding the impact of full vacuum pressures along DIP.

Based on the above and using engineering judgement, the following criteria were established to characterize effective mitigation of the transient impact (upsurge and downsurge) as not to exceed values at any node and in any instant throughout the duration of the model run:

- **Maximum Allowable Surge Pressure:** Test pressure as measured by HGL shown on .
- **Minimum Allowable Surge Pressure:** -10 psi (globally).

5.1.5 Solution (Mitigated) Transient Impact Simulations

The transient mitigation strategy focused on the installation of Combination Air Valves (CAVs) along the pipeline and a surge tank located at the RFPS. Preliminary simulations showed that a surge tank of closed type (air chamber) could drastically reduce the number of CAVs needed to achieve effective transient control by as much as 15-20 CAVs, thereby also reducing the number of single points of failure for worst-case transient scenarios. These simulations also confirmed that a surge relief valve would have no practical contribution in controlling the type of transients that this system is susceptible to. Therefore, such a solution was not pursued. Subsequent runs focused on optimizing the parameters of the tank so that maximum benefit is achieved at minimum cost.

The final configuration of transient mitigation measures included the following:

- **Surge Tank:** A surge tank at the RFPS with a minimum volume of 1,523 cubic feet, connected to the main pipeline through a 30-inch diameter pipe, which could have a maximum length of 36 feet. The initial gas volume in the tank should be set at 825 cubic feet.
- **Combination Air Valves (CAVs):** Two critical 4-inch diameter CAVs installed respectively at the Return Flow Pipeline's global and hydraulic high points. Note that the CAV at the hydraulic high point was upsized to 6-inches for air management as described in **Section 5.2**.

The instantaneous transient HGL obtained for this final mitigated scenario is shown in **Figure 5-3**. Pressure upsurges are consistently contained to levels below 150 psi. For the majority of the pipeline, the maximum pressure coincides with that obtained during steady state conditions. Furthermore, at no system point did the downsurge assume values below the minimum allowable surge pressure. As a consequence, vacuum pressures did not materialize and no vapor cavities were formed. These results are also evident in the pressure signals for this model case.

5.1.6 Conclusions and Recommendations

The transient analysis of the Return Flow Pipeline can be effectively summarized with the following conclusions, recommendations and considerations:

Conclusions:

- Effective protection (within the established maximum and minimum allowable surge pressure thresholds) will be obtained through a surge tank and two critical CAVs as described above.
- No special flow control protocols are necessary to achieve the transient mitigation reported here.
- The pressure classes selected based on steady state hydraulics suffice to withstand transient hydraulics.

- The performance of transient mitigation appurtenances depends on the condition that these are adequately maintained and fully-functioning.

Recommendations:

- Findings and recommendations of this Report are contingent upon the selection of equipment in the RFPS being designed by others that will be reasonably similar to the ones used in development of the transient hydraulic model of the RFPS. In case the specifications differ, the model and its results will need to be revisited to confirm hydraulic transients is properly mitigated. Similarly, additional transient evaluations will be warranted if new infrastructure is installed at the Outfall Facilities to provide for energy recovery or water reuse.
- If comments are received from permitting agencies or authorities having jurisdiction that alters the pipeline alignment, the transient hydraulic model will be simulated based on the final pipeline alignment to confirm these findings. Any minor changes in the size and location of air valves would be completed prior to bidding.
- The Return Flow Pipeline Operations and Maintenance Manual (to be developed during construction of the Program) should incorporate pertinent operational protocols and recommendations related to the two critical transient mitigating CAVs. It is recommended a similar manual be developed for the new RFPS and surge tank in relation to pertinent operational protocols and recommendations to support transient mitigation of the return flow system. Such recommendations will include protocols that account for when the surge tank is inoperable and establish the discharge that can be pumped without risking the development of catastrophic transients.
- The transient mitigation measures in this Report pertain to the part of the system designed by the Program for the Return Flow Pipeline (CAVs for the Return Flow Pipeline) and to a specific countermeasure (surge tank) proposed for the design of the RFPS. This does not preclude other options for transient mitigation at the RFPS (for example, retrofitting the pumps with flywheels to increase the inertia of the system).
- Transients due to pumps' startup (or re-start after a failure) can be controlled by: 1) slowly introducing water into the pipeline and 2) having pumps turned on one-at-a-time, until the Return Flow Pipeline is primed from the RFPS to the hydraulic high point.
- The transient hydraulic model of the RFPS and Return Flow Pipeline is a digital asset for WWU and Waukesha. As such, it is strongly recommended to be maintained beyond the design phase, so that the return from the investment for its development can be maximized. The capabilities of this "digital twin" of the physical system can be leveraged to achieve a variety of goals including optimization of operations, troubleshooting, and evaluation of future infrastructure upgrades.

5.2 Air Management

In addition to hydraulic transients, air valves are required to provide for air management along the Return Flow Pipeline. The following sections describe how air valves were also sized to manage air along the pipeline.

5.2.1 Air Release Valves (ARVs)

Air release valves (ARVs) exhaust small pockets of accumulated air that collect at high points during the normal operation of the pipeline. The presence of air pockets reduces the capacity of the pipe and increases head loss. It is, therefore, critical to make provisions for the effective removal of entrapped air, so that the entire system can operate efficiently. ARVs are designed to expel air in a controlled fashion and at modest rates, so that the risk from secondary transients due to a rapid expulsion of air is mitigated (Apollonio et al., 2016). For this reason, ARVs have a small orifice and are typically furnished in inlet sizes from 0.5 to six inches.

5.2.1.1 Methodologies for Locating and Sizing ARVs

5.2.1.1.1 AWWA M51

The selection and design of ARVs was primarily based on the guidelines of AWWA as detailed within the most recent edition of AWWA M51 (2016). Such recommendations are the industry's standard for the selection of design parameters such as the orifice size and location. The calculations were based on the flow rate of 14.5 MGD and the assumption of 5% solubility of gas in the highly treated effluent flowing in the Return Flow Pipeline (at standard pressure and temperature). This methodology was applied over the length of the pipeline.

5.2.1.1.2 Dimensionless Discharge Criterion

Air entrainment and movement in pipelines with gravity-driven flow is an active topic of research. The peer-reviewed literature includes a number of studies that have investigated the phenomenon using experimental, field and numerical methods (Pozos et al, 2010, Zhou et al., 2002). One of the key findings, which is also of practical use for the design and operation of real-life systems, is the so-called dimensionless discharge criterion expressed as:

$$\frac{Q^2}{gD^5} = S$$

where, Q is the volumetric flow rate of water; g the gravitational acceleration; D the pipe diameter, and S the pipe's slope. This criterion is a simple, yet effective way to evaluate the potential of air accumulation and the subsequent direction of air movement within a pipeline. If the left-hand side of the equation is greater than the slope, then any air pockets are expected to move along the flow direction. In the opposite case, air pockets will move against the flow direction and will become entrapped at the upstream end of the pipe segment. This entails the installation of an ARV. The dimensionless discharge criterion was applied throughout the gravity-driven segment of the Return Flow Pipeline. The flow rates used for this evaluation included: a) the maximum instantaneous flow rate (14.5 MGD); b) the initial average day demand (6.6 MGD), and c) a minimum flow rate (1.2 MGD).

5.2.2 Air/Vacuum Valves (AVVs)

Air / Vacuum Valves (AVVs) serve the dual purpose of venting large quantities of air during pipe filling and admitting large quantities of air during pipe draining. Expelling the air present in the pipe as filling progresses is important because it prevents the formation of large air pockets in the pipeline. AVVs also prevent a vacuum from forming in the pipeline by allowing large volumes of air to be quickly admitted into the pipeline. Breaking the vacuum is an effective means to mitigate transient cavitation, which can occur during draining, pipe break, or other transient flow conditions. They are typically installed downstream of pumps and at high points in the system. It is important to note that AVVs are normally closed based on normal operating pressure and will not relieve the pipeline of small amounts of air. AVVs have a larger orifice and are available in inlet sizes from 0.5 to 30 inches.

5.2.2.1 Methodologies for Locating and Sizing AVVs

5.2.2.1.1 AWWA M51 – Pipe Filling and Emptying

When the Return Flow Pipeline is drained or filled for maintenance or emergency situations during operations, the air in the pipeline will need to be vented at the same rate that water flows into the pipeline. In accordance with AWWA M51, the pipeline should be drained and filled in a controlled manner with water flowing at approximately one fps. This translates into flow rates of 2,200 gpm for the 30-inch diameter Return Flow Pipeline. Note that this fill rate does not apply to the initial filling of the pipeline, as the contractor may allow air to be expelled through blow-offs or other larger openings to allow a quicker fill rate. The second parameter to size AVVs is the pressure differential driving the flow of air. A target value of 2 psi was selected to maintain relatively low air speeds through the valve's orifice and, therefore, mitigate side-effects due to turbulence, valve slam and pressure spikes (Ramezani et al., 2015). The information will be included in the Return Flow Pipeline Operations and Maintenance Manual.

The number, location, and size of AVVs calculated for the pipe filling phase should suffice to allow air to flow in at the same rate as that of the water leaving the system during pipe draining. AWWA M51 calculations for filling and draining were applied throughout the pipeline.

5.2.2.1.2 AWWA M51 – Transient Mitigation (Gravity Flow)

AWWA has published an analytical methodology for AVV sizing to mitigate the impact from transient-inducing events, such as power failures and pipeline breaks. Essentially, the goal is to control the resulting gravity flow, so that vacuum conditions and its adverse effects (column separation, transient cavitation) are avoided. The approach is relatively simple and relies on the installation of an AVV at every local high point along the pipeline. AVV sizing is performed based on the selection of the appropriate flow rate based on the allowable differential pressure of 5 psi needed to prevent pressures in the pipe from exceeding the threshold of collapse.

By definition, this broad methodology encompasses a high degree of conservatism. In systems where a hydraulic transient model is available, it could serve as a means to cross-reference the results from the detailed numerical analysis. For the Return Flow Pipeline, the AWWA M51 Transient Mitigation (Gravity Flow) method was used to locate and size AVVs for the portion of the system where flow is driven by gravity and transient analysis is beyond the capabilities of the modeling software.

5.2.2.1.3 AWWA M51 – Open-Channel Transitions

As mentioned in **Section 3**, segments of the Return Flow Pipeline downstream of the hydraulic control point will experience open channel flow conditions. These transitions between flow regimes warrant additional analyses to locate and size AVVs that would effectively control the extra volume of air.

The steady state hydraulic model was used to size and locate anticipated open channel flow sections of the pipeline at the transition between the operational extremes of the maximum instantaneous flow rate (14.5 MGD) and the minimum flow rate (1.2 MGD). The goal was to determine the difference in volume of the "headspace" for both flow cases. Then, a minimum time of 5 minutes was selected as the time to complete transition between these two flow states (low to high flow and vice versa). This procedure concluded with the calculation of the required flowrate of air, and the sizing of the AVV orifice using Table 4-2 of AWWA M51.

5.2.2.1.4 LIQT Transient Hydraulic Modeling

The last method for locating and sizing AVVs to mitigate the transient impact involves the development and use of a model capable of detailed transient hydraulic simulations. The results from the LIQT model for the return flow system have been presented in this section. Note the application of the model for locating and sizing AVVs is limited to the pump-driven section of the system.

5.2.3 Combination Air Valves (CAVs)

CAVs combine the functions of an ARV with an AVV into one unit. Therefore, there is an economic benefit when both valve types are needed at the same location. CAVs contain both a small orifice for air release and a large orifice for large air release/vacuum into one assembly. Some applications will require an ARV and AVV to be manifolded together to provide benefits of both with a wider selection than what is offered with a single-body design. Single body CAVs are available in inlet sizes from one to eight inches, where dual body CAVs are available from one to 36 inches. Single and dual body CAVs were designed for smaller than 3 inches and 3 inches and larger, respectively.

5.2.3.1 Methodologies for Locating and Sizing CAVs

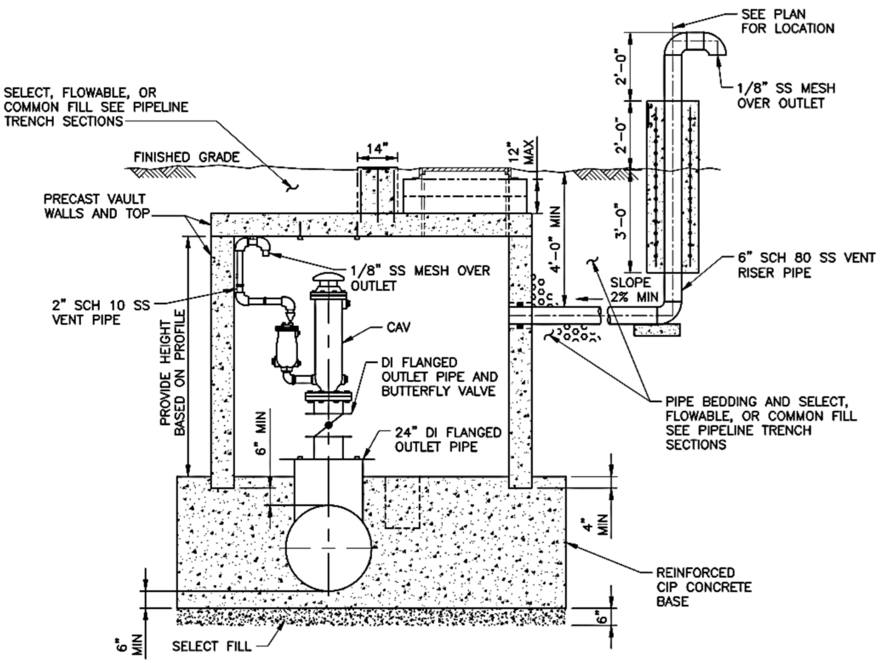
Since the installation of CAVs is simply a cost-effective means to obtain the benefits of both ARVs and AVVs, there was no need to apply additional methodologies to locate and size ARVs and AVVs. After review of the resulting locations of ARVs and AVVs, it was determined the Return Flow Pipeline would be provided with only CAVs at the locations and with the types and sizes recommended in the above sections. This approach also provides for ease of maintenance and operations, by reducing the number of different types and sizes of air valves that may be desired as spare parts during operations. Seat durometers were determined based on the maximum normal operating pressure per manufacturer recommendations. Two air valve assemblies were designed for redundancy where required to mitigate hydraulic transients.

5.3 Air Valve Design

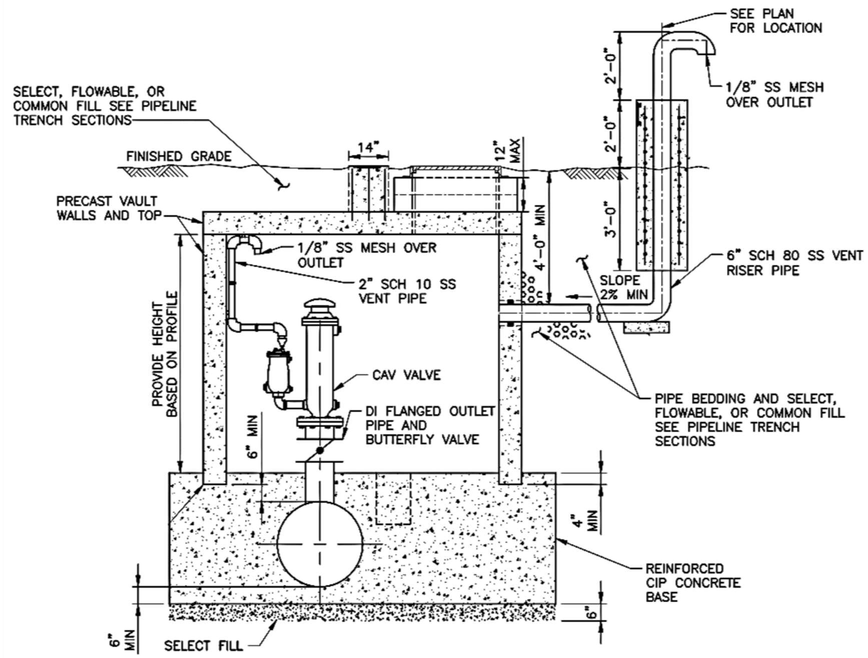
Air valves for the Return Flow Pipeline were designed based on the hydraulic transient modeling results and methods used to size air valves for air management purposes. Air valve assembly details are shown in **Figure 5-2**. The size, type, number of air valves, and seat durometer are summarized in **Table 5-2** and the locations of the air valve assemblies are shown in **Figure 5-3.**

Table 5-2 Air Valve Assembly Schedule

Air Valve ID	Type	Size (in)	No. of Air Valves	Durometer Seat	Air Valve ID	Type	Size (in)	No. of Air Valves	Durometer Seat
AV-RF01	I	4	1	Standard	AV-RF19	II	10	1	Low
AV-RF02	I	4	1	Standard	AV-RF20	I	2	1	Standard
AV-RF03	II	4	1	Standard	AV-RF21	II	6	1	Standard
AV-RF04	I	4	1	Standard	AV-RF22	II	4	1	Standard
AV-RF05	II	4	1	Standard	AV-RF23	I	10	1	Standard
AV-RF06	I	4	1	Standard	AV-RF24	I	6	1	Standard
AV-RF07	II	4	1	Standard	AV-RF25	I	4	1	Standard
AV-RF08	I	4	2	Low	AV-RF26	II	6	1	Low
AV-RF09	I	4	1	Low	AV-RF27	I	6	1	Low
AV-RF10	I	4	1	Standard	AV-RF28	II	4	1	Low
AV-RF11	I	6	2	Low	AV-RF29	I	6	1	Low
AV-RF12	II	4	1	Standard	AV-RF30	I	6	1	Low
AV-RF13	II	6	1	Standard	AV-RF31	II	4	1	Low
AV-RF14	I	6	1	Standard	AV-RF32	I	6	1	Low
AV-RF15	I	6	1	Low	AV-RF33	I	6	1	Low
AV-RF16	II	6	1	Low	AV-RF34	I	6	1	Low
AV-RF17	I	8	1	Standard	-	-	-	-	-
AV-RF18	II	8	1	Standard					



Section – Type I, With Access



Section – Type II, Without Access

Figure 5-2 Air Valve Assembly Details

Notes:

1. The air valves were designed with a screened gooseneck within the vault and a vent riser pipe was designed from the vault to grade in accordance with NR 811.71.
2. Type I air valve assemblies were placed at maximum intervals of 8,000 feet to allow access to the inside of the pipeline for inspection purposes. The remainder of the air valves were designed as Type II air valve assemblies to minimize cost.

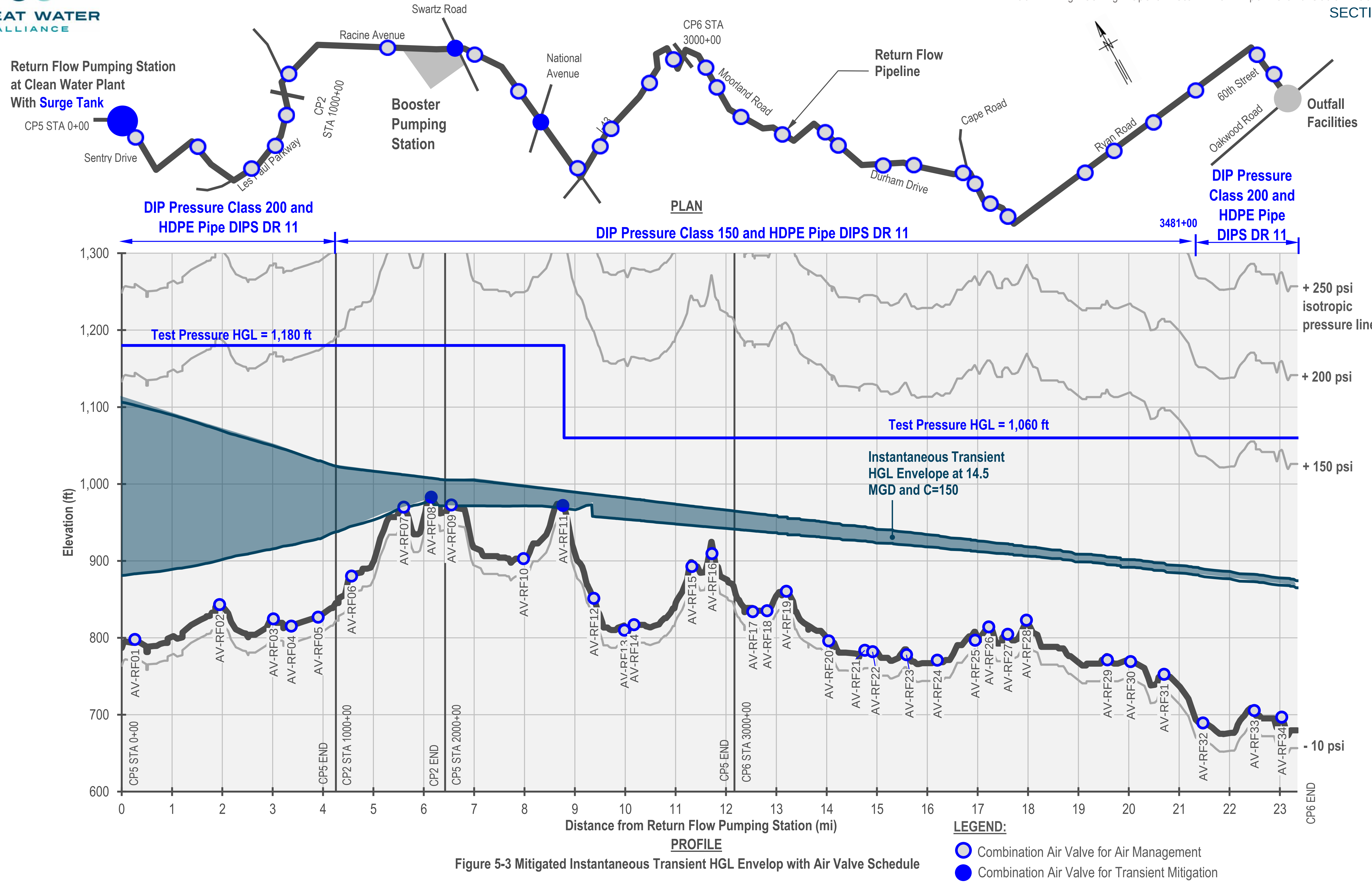


Figure 5-3 Mitigated Instantaneous Transient HGL Envelop with Air Valve Schedule

SECTION 6 Program Return Flow Pipeline and Outfall Facility Costs

6.1 Opinion of Probable Construction Cost (OPCC)

An OPCC has been prepared in accordance with the AACE International's Recommended Practice No. 18R-97. The OPCC was developed using unit cost information from various resources in an effort to provide the best available information for each item, including manufacturer quotes, RS Means, and bid tabs from Southeast Wisconsin and Northeast Illinois. The diagram shown in **Figure 6-1** demonstrates the projected accuracy of the OPCC as the Program progresses as adapted from AACE International guidance. The OPCC in this document has been defined as Class 1 OPCC as shown in blue in **Figure 6-1**.

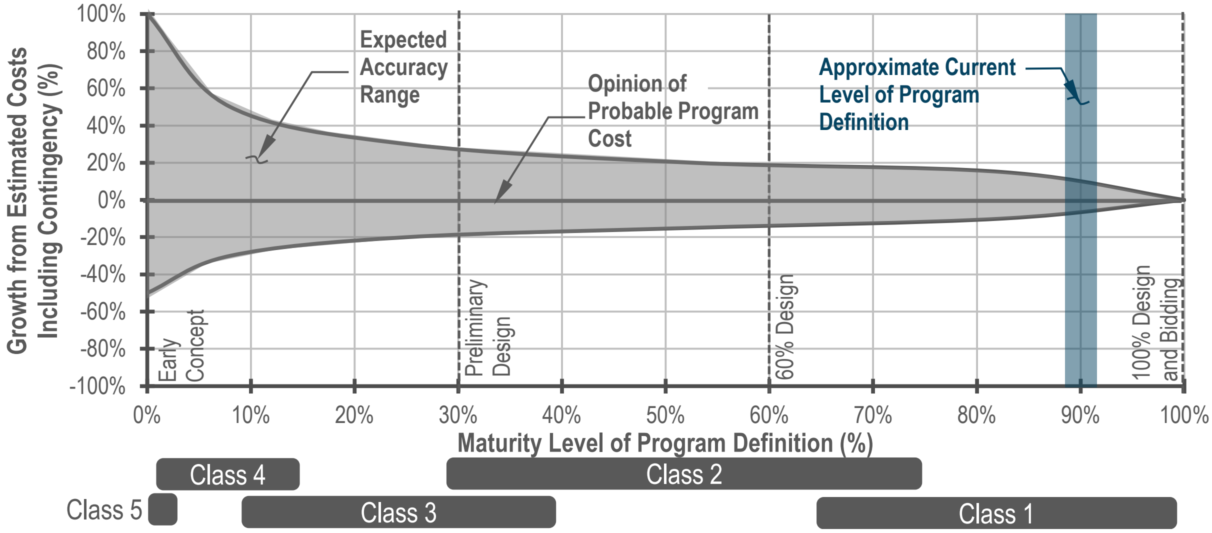


Figure 6-1 Cost Opinion Accuracy Diagram

Table 6-1 provides a Class 1 OPCC for each contract package associated with WWU's new return flow system. The contract packages that are part of the Program, but are paid for by entities other than WWU, have been included for reference. The OPCC was developed with a contingency of 15% and escalated to January 2021 dollars, which is the approximate midpoint of construction.

Table 6-1 Opinion of Probable Construction Cost

Contract Package		OPCC	
No.	Description	($ Million)	Notes
1	Oklahoma Pumping Station	-	See Note 1
2	Return Flow Pipeline, BPS Discharge Pipeline, Water Supply Pipeline Sections I, II, and III, and Station Suction Pipelines	7.1	See Note 2
3	Booster Pumping Station, Storage, and Chemical Facilities	-	See Note 1
4	Return Flow Pumping Station	-	See Note 3
5	Return Flow Pipeline	35.0	-
6	Return Flow Pipeline, 18-Inch Sanitary Sewer, and Outfall Facilities	52.3	-
	Total WWU Water Supply System Opinion of Probable Construction Cost	62.9	

<u>**Notes:**</u>

1. The Contract Package includes only infrastructure that supports WWU's new water supply system and has been excluded from this Report.
2. The BPS Discharge Pipeline, Water Supply Pipeline, and Station Suction Pipelines are part of WWU's new water supply system and are excluded from this OPCC.
3. WWU is not paying for Contract Package 4.

6.2 Operation, Maintenance and Replacement (OM&R)

OM&R costs have been developed to provide opinions of annual and Net Present Value (NPV) costs for WWU's new return flow system. The OM&R and NPV costs presented herein encompass the Program Elements of the new return flow system that WWU will own, operate and maintain.

The key assumptions used to develop the OM&R costs include the following items.

- NPV Gradient Series for a 20-year planning period, which is consistent with WDNR guidance on monetary analysis in NR 110, and an 8% Discount Rate and 3% Inflation Factor.

The Program OM&R cost requirements were developed for WWU's Return Flow Pipeline and Outfall Facilities. The OM&R costs were escalated to July 2023 dollars. **Table 6-2** provides a summary of the Return Flow System Program facilities costs.

Table 6-2 Summary of Annual OM&R Costs

Description	OM&R Cost ($)
New Return Flow System Facilities and Pipelines OM&R Cost Total	$230,000

SECTION 7 Conclusions

Under the Wisconsin Administrative Code NR 108.04(2)(a), "All final plans and specifications submitted to the department pursuant to s. 281.41, Stats., and s. NR 108.03, shall be accompanied by a request for approval and by information pertinent to the design of the system, including general plans, construction details, specifications and an engineering report." The purpose of this Report is to satisfy this requirement for the Return Flow Pipeline being implemented as part of the Program by summarizing the approach used for making key design decisions that supported the development of the drawings and specifications, including the following:

- Key design philosophies, including pipe materials, alignment, pipeline appurtenances, and corrosion control.
- The approach for modeling steady state hydraulics, designing pipe size, test pressures, pipe pressure class, and restrained joints, and determining normal operating conditions.
- The approach for modeling transient hydraulics, determining the type, size, and location for pipeline appurtenances required to mitigate hydraulic transients, and providing provisions for air management.

Route Study and Field Investigations

A route study was completed for the Return Flow Pipeline. Route alternatives were identified between a new Return Flow Pumping Station located at the City of Waukesha's CWP and the new Outfall Facilities located on the southeast quadrant of Oakwood Road and 60th Street in the City of Franklin. The route alternatives were evaluated based on economic and non-economic evaluation criteria and scored via a Triple Bottom Line analysis guided by the Envision Rating System for Sustainable Infrastructure. Route Alternative 3 was selected as the route for the Return Flow Pipeline. Field investigations, including site survey, geotechnical, environmental, wetlands, waterways, endangered resources, and cultural resources were subsequently completed to support design.

Steady State Hydraulics

The Return Flow Pipeline is required to return the volume of water conveyed to Waukesha back to the Great Lakes-St. Lawrence River Basin. The Return Flow Pipeline was designed to convey flows reflective of Waukesha's water demand. The design capacity for the Return Flow Pipeline is based on the maximum day demand of 13.6 MGD during a year with an average day demand equivalent to the average day demand approved by the Compact Council of 8.2 MGD. A maximum instantaneous flow rate of 14.5 MGD was used as a secondary design criterion to accommodate flexibility in pumping schedules or the potential for future expansion of the Return Flow Pumping Station.

A steady state hydraulic model for the Return Flow Pipeline was developed based on the pipeline alignment. Topography allows the ability for the Return Flow Pipeline to be operated as either a force / gravity main or entirely as a force main, which would allow the potential for energy recovery and water reuse in the future with additional infrastructure required at the Outfall Facilities. The Program determined the Return Flow Pipeline will be initially operated as a force / gravity main, but would be designed to allow for either hydraulic condition to be conveyed in the future. Thus, hydraulics for the Return Flow Pipeline were simulated as both a force / gravity main and entirely as a force main from static conditions (no flow) to 14.5 MGD. From the hydraulic analysis, a 30-inch Return Flow Pipeline size was selected. Test pressures were determined in accordance with AWWA C600, and pipe pressure classes and restrained joints were designed based on the test pressures.

Design Philosophy

Pipe materials and joints were designed based on pipe size, hydraulics, constructability, WWU familiarity with material, and cost. To mitigate corrosion and provide for a longer service life, the Return Flow Pipeline was designed with two layers of polyethylene encasement – an inner layer consisting of V-Bio® Enhanced Polyethylene Encasement and an outer layer of standard polyethylene encasement, as well as sacrificial galvanic magnesium anodes, bonded joints, and test stations. The test stations will allow the ability to periodically monitor for corrosive signatures during operations so that proactive corrosion mitigation measures can be implemented if needed.

The horizontal and vertical alignments were developed for the pipeline considering pipe materials, joints, and construction methods, including open-cut and trenchless construction. Construction methods were selected based on surface features, existing utilities, and cost. Trenchless construction was utilized in areas where open-cut construction was not specifically preferred due to surface features or permit requirements. Horizontal and vertical alignments of the pipeline were designed beyond pavement where feasible to reduce cost due to pavement replacement, flowable or select fill, and maintenance of traffic. Trenchless construction via jacking and boring was utilized as a means of mitigating surface disruption at rail and major road crossings and HDD was utilized to cross waterways and select wetlands. Limits of construction were designed to accommodate the construction method and pipeline appurtenances.

Pipeline appurtenances were designed for operations and maintenance as follows.

- **Isolation Valves:** The pipeline was designed with butterfly valves that will serve to isolate portions of the pipeline for maintenance and repair scenarios. Isolation valves were placed at approximately two-mile intervals, while some valves were shifted towards trenchless construction segments to minimize additional restrained joint length. Isolation valves were designed to be direct buried except where specifically required to be located in vaults by the Wisconsin Administrative Code.
- **Blow-Off Assemblies:** Blow-off assemblies, consisting of a tee, branch, gate valve, and riser pipe, were placed at local low points in the vertical alignment to provide a means for draining the pipeline during startup, maintenance, or repair scenarios.
- **Air Valve Assemblies:** Air valves were placed at local high points along the vertical alignment to provide provisions for air management and transient mitigation. The air valve assemblies were designed in vaults with provisions for accessing the inside of the pipeline for inspection purposes at maximum intervals of 8,000 feet.

Transient Hydraulics and Air Management

A transient hydraulic model for the Return Flow Pipeline was developed in LIQT software based on the pipeline alignment. Hydraulics were simulated for a sudden loss of power and stoppage of pumping while conveying 14.5 MGD. Transient mitigation devices in the form of air valve assemblies and a surge tank located at the new Return Flow Pumping Station were designed to mitigate hydraulic transients. Air valve assemblies were also designed to maintain capacity during normal operation by releasing entrained air and to accommodate filling and emptying during startup and operations. Refer to **Section 5** for air valve locations.

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